

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS.

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE,
W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS,
LOUIS V. PIRSSON, HERBERT E. GREGORY
AND HORACE S. UHLER, OF NEW HAVEN,

PROFESSOR HENRY S. WILLIAMS, OF ITHACA,
PROFESSOR JOSEPH S. AMES, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

WITH TEN PLATES.

NEW HAVEN, CONNECTICUT.

1913.

227167

THE TUTTLE, MOREHOUSE & TAYLOR COMPANY
NEW HAVEN



CONTENTS TO VOLUME XXXVI.

Number 211.

	Page
ART. I.—Investigation of the Prehistoric Human Remains found near Cuzco, Peru, in 1911; by H. BINGHAM	1
II.—Vertebrate Remains in the Cuzco Gravels; by G. F. EATON	3
III.—Gravels at Cuzco, Peru; by H. E. GREGORY	15
IV.—Simple Model for Illustrating the Symmetry of Crystals; by A. H. PHILLIPS	30
V.—Chemical Composition of the Alkaline Rocks and its Significance as to their Origin; by C. H. SMYTH, Jr.	33
VI.—Solid Solution in Minerals. III. The Constant Composition of Albite; by H. W. FOOTE and W. M. BRADLEY ..	47
VII.—Triplite from Eastern Nevada; by F. L. HESS and W. F. HUNT	51
VIII.—Heat of Formation of the Oxides and Sulphides of Iron, Zinc and Cadmium, etc.; by W. G. MIXTER	55
IX.—Deep Boring in Bermuda Island; by L. V. PIRSSON and T. W. VAUGHAN	70
X.—Preparation of Telluric Acid and Test for Associated Tellurous Acid; by P. E. BROWNING and H. D. MINNIG ..	72

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Compounds of Trivalent and Quadrivalent Tungsten, O. OLSSON: New Oxide of Carbon, H. MEYER and K. STEINER, 73.—Examination of Waters and Water Supplies: Gas Analysis: Chemical Analysis for Students of Medicine, 74.—Per-Acids and their Salts: Practical Physiological Chemistry, 75.—Influence of Dissolved Salts on the Absorption Bands of Water, 76.

Geology and Natural History—United States Geological Survey, 77.—Bureau of Mines, United States: Geological Survey of New Jersey, 78.—Map of West Virginia, showing Coal, Oil, Gas, Iron Ore and Limestone Areas: Living and Fossil Flora of West Virginia: Wisconsin Geological and Natural History Survey: Iron making in Alabama: Canada Department of Mines, 79.—Underground Water Resources of the Coastal Plain Province of Virginia: Geology of the Columbus Quadrangle, 80.—State Geological Survey of Wyoming, Bulletin 3, Series B: Coal, and the Prevention of Explosions and Fires in Mines: New Zealand Department of Mines, 81.—Geology and Ore Deposits of the Monarch and Tomichi Districts: Devonian and Mississippian formations of N.E. Ohio, 82.—Fossil Coleoptera from the Wilson Ranch near Florissant, Col.: Lower Siluric shales of the Mohawk valley, 83.—Introduction to Zoology: Malaria, Cause and Control: Publications of the British Museum of Natural History, 84.—Annual Report of the Director of the Field Museum of Natural History, 86.

Miscellaneous Scientific Intelligence—General Index to the Chemical News, Vols. 1 to 100, 86.—Journal of Ecology: Annual Report of Superintendent of Coast and Geodetic Survey, 87.—Hurricanes of West Indies: Die Zersetzung und Haltbarmachung der Eier: Publications of Comitato Talassografico Italiano, 88.—Publications of Allegheny Observatory of University of Pittsburgh: Publications of Detroit Astronomical Observatory of the University of Michigan: Carothers Observatory: Bibliotheca Zoologica II, 89.—Chemical and Biological Survey of Waters of Illinois: Mining World Index of Current Literature, Vol. II, 90.

Obituary—E. KITTL: J. G. MACGREGOR: LORD AVEBURY: W. HALLOCK, 90.

Number 212.

	Page
ART. XI.—Velocities of Delta Rays ; by H. A. BUMSTEAD	91
XII.—Banded Gneisses of the Laurentian Highlands of Canada ; by M. E. WILSON	109
XIII.—Deep Wells at Findlay, Ohio ; by D. D. CONDIT	123
XIV.—Note on the Temperature in the Deep Boring at Findlay, Ohio ; by J. JOHNSTON	131
XV.—Arc Spectrum of Tellurium ; by H. S. UHLER and R. A. PATTERSON	135
XVI.—La Paz (Bolivia) Gorge ; by H. E. GREGORY	141
XVII.—Some Kilauean Formations ; by F. A. PERRET	151
XVIII.—Marked Unconformity between Carboniferous and Devonian Strata in Upper Mississippi Valley ; by C. R. KEYES	160
XIX.—Meteoric Iron from Paulding County, Georgia ; by T. L. WATSON	165
XX.—Pyroxmangite, a New Member of the Pyroxene Group and its Alteration Product, Skemmatite ; by W. E. FORD and W. M. BRADLEY	169
XXI.—New or little known Paleozoic Faunas from Wyo- ming and Idaho ; by E. BLACKWELDER	174
XXII.—Solid Solution in Minerals. IV. The Composition of Amorphous Minerals as illustrated by Chrysocolla ; by H. W. FOOTE and W. M. BRADLEY	180

SCIENTIFIC INTELLIGENCE.

Miscellaneous Scientific Intelligence—History of the first Half-Century of the National Academy of Sciences, 1863-1913, 185.—United States Geological Survey, 186.

Obituary—E. HOLZAPFEL, 186.

Number 213.

	Page
ART. XXIII.—Geologic Sketch of Titicaca Island and Adjoining Areas; by H. E. GREGORY. (With Plate I)	187
XXIV.—Experiments on Columnar Ionization; by E. M. WELLISCH and J. W. WOODROW	214
XXV.—Geology of the New Fossiliferous Horizon and the Underlying Rocks, in Littleton, N. H.; by F. H. LAHEE	231
XXVI.—Liassic Flora of the Mixteca Alta of Mexico,—Its Composition, Age and Source; by G. R. WIELAND....	251
XXVII.—Age of the Eurypterids of Kokomo, Indiana; by E. M. KINDLE	282
XXVIII.—Two Vanadiferous Ægirites from Libby, Montana; by E. S. LARSEN and W. F. HUNT	289
XXIX.—Method of Increasing and Controlling the Period in Vertical Motion Seismographs; by F. A. PERRET...	297
XXX.—Action of Sodium Paratungstate in Fusion on Salts of the Halogen Acids and Oxy-halogen Acids; by S. B. KUZIRIAN	301
XXXI.—Use of the Sodium Paratungstate and the Blowpipe Flame in the Determination of the Acid Radicals of Chlorides, Chlorates, Perchlorates, Bromides, Bromates and Fluorides; by S. B. KUZIRIAN	305

SCIENTIFIC INTELLIGENCE.

Miscellaneous Scientific Intelligence.—Atlas der Krystallformen, V. GOLDSCHMIDT: Dybdeboring i Grøndals eng ved København 1894-1907 og dens videnskabelige Resultater, E. P. BONNESEN, O. B. BÖGGILD og J. P. RAVN, 313.—Das Problem der Vererbung "Erworbener Eigenschaften", R. SEMON: Principles of Economic Zoölogy; Part I, Field and Laboratory Guide, L. S. DAUGHERTY and M. C. DAUGHERTY: The Modern Worship, E. L. ATWOOD, 314.

Number 214.

	Page
ART. XXXII.—Distribution of the Active Deposit of Radium in an Electric Field (II); by E. M. WELLISCH	315
XXXIII.—Adjustment of the Quartz Spectrograph; by C. C. HUTCHINS	328
XXXIV.—Stability Relations of the Silica Minerals; by C. N. FENNER	331
XXXV.—Custerite: A New Contact Metamorphic Mineral; by J. B. UMPLEBY, W. T. SCHALLER, and E. S. LARSEN	385
XXXVI.—Ordovician Outlier at Hyde Manor in Sudbury, Vermont; by T. N. DALE	395
XXXVII.—Preparation of Tellurous Acid and Copper Ammonium Tellurite; by G. O. OBERHELMAN and P. E. BROWNING	399
XXXVIII.—Determination of Water of Crystallization in Sulphates; by S. B. KUZIRIAN	401
XXXIX.—Paleozoic Section in Northern Utah; by G. B. RICHARDSON	406

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Volatile Oxide of Manganese, F. R. LANKSHEAR: Detection of Bromine and its Distribution in Nature, I. GUARESCHI, 416.—Calcium Hydride, MOLDENHAUER and ROLL-HANSEN: Analysis of Special Steels, S. ZINBERG, 417.—Qualitative Chemical Analysis, A. A. NOYES: New Fluorescence Spectrum of Iodine, J. C. MCLENNAN, 418.—Interference of Gamma Rays, A. N. SHAW, 420.—Experimental Researches on the Specific Gravity and Displacement of Some Saline Solutions, J. Y. BUCHANAN, 421.—Elektrischen Eigenschaften und die Bedeutung des Sels für die Elektrotechnik, C. RIES: Photochemische Versuchstechnik, J. PLOTNIKOW, 422.—First Course in Physics, R. A. MILLIKAN and H. G. GALE: Materialien für eine wissenschaftliche Biographie von Gauss, F. KLEIN and M. BRENDL, 423.—Descrizione di una Macchinetta Elettromagnetica, A. PACINOTTI: L'attraction universelle considérée comme fonction du temps, A. N. PANOFF, 424.

Geology and Mineralogy—Publications of the United States Geological Survey, 424.—Report of the State Geologist on the Mineral Industries and Geology of Vermont, 1911-12: Cretaceous deposits of Miyako, H. YABE and S. YEHARA, 425.—Die Antike Tierwelt, O. KELLER: A Manual of Petrology, F. P. MENNELL, 426.—Supposed new occurrence of Plattnerite in the Coeur d'Alene, E. V. SHANNON, 427.

Miscellaneous Scientific Intelligence—Müller's Serodiagnostics Methods, R. C. WHITMAN: Planetologia, E. CORTESE, 428.

Number 215.

	Page
ART. XL.—Upper Devonian Delta of the Appalachian Geosyncline ; by J. BARRELL	429
XLII.—Optical Bench for Elementary Work ; by H. W. FARWELL	473
XLII.—Volcanic Research at Kilauea in the Summer of 1911 ; by F. A. PERRET ; with Report by A. BRUN	475
XLIII.—Observations on the Stem Structure of <i>Psaronius Brasiliensis</i> ; by O. A. DERBY	489
XLIV.—Fauna of the Florissant (Colorado) Shales ; by T. D. A. COCKERELL	498
XLV.—The Photoelectric Effect ; by L. PAGE	501
XLVI.—Graphical Methods in Microscopical Petrography ; by F. E. WRIGHT. (With Plates II to IX)	509
XLVII.—A Graphical Plot for Use in the Microscopical Determination of the Plagioclase Feldspars ; by F. E. WRIGHT. (With Plate X)	540
XLVIII.—On the Influence of Alcohol and of Cane Sugar upon the Rate of Solution of Cadmium in Dissolved Iodine ; by R. G. VAN NAME and D. U. HILL	543
XLIX.—Comparative Studies of Magnetic Phenomena. IV. Twist in Steel and Nickel Rods due to a Longitudinal Magnetic Field ; by S. R. WILLIAMS	555

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Hydrides of Boron, A. STOCK : Metallic Beryllium, FICHTER and JABLONZYNSKI, 562.—General Chemistry, Theoretical and Applied, J. C. BLAKE : A Dictionary of Applied Chemistry : General and Industrial Organic Chemistry, 563.—Chemistry and its Relations to Daily Life : Studies in Valency : Deviation of Rubidium Rays in Magnetic Fields, K. BERGWITZ, 564.—Researches in Magneto-Optics, P. ZEEMAN : A New Element, Uranium X : Mechanics and Heat, 565.—Practical Physics for Secondary Schools : Beyond the Atom, 566.—Physikalische Chemie der homogen und heterogenen Gasreaktionen, 567.

Geology—Virginia Geological Survey : Sixteenth Annual Report of the Geological Commission, Cape of Good Hope, Department of Mines, 1911 (1912), 568.—Sixth Annual Report (New Series) of the New Zealand Geological Survey, Session II, 1912 : Geological Survey of Western Australia, 1912, 569.—Recurrent Tropidoleptus zones of the Upper Devonian in New York : Grundzüge der geologischen Formations- und Gebirgskunde : Igneous Rocks, J. P. IDDINGS, 571.—Introduction to the Study of Igneous Rocks, G. I. FINLAY, 573.—Der Vulkanismus, 574.

Miscellaneous Scientific Intelligence—Publications of the Carnegie Institution of Washington, 575.—The Mining World Index of Current Literature, 576.

Obituary—C. G. ROCKWOOD : J. R. EASTMAN : A. MACFARLANE : J. MILNE : W. N. HARTLEY : H. MARSHALL : P. L. SCLATER : H. CREDNER : H. LASPEYRES : H. WEBER, 576.

Number 216.

	Page
ART. I.—Some Lavas of Monte Arci, Sardinia ; by H. S. WASHINGTON	577
II.—On the Use of Sealing Wax as a Source of Lime for the Wehnelt Cathode ; by NELLIE N. HONOR	591
LII.—Dehydration and Recovery of Silica in Analysis ; by F. A. GOOCH, F. C. RECKERT and S. B. KUZIRIAN	598
LIII.—The Ascent of Lava ; by F. A. PERRET	605
LIV.—Solar Radiation ; by F. W. VERY	609
LV.—A New Occurrence of Cuprodesclowitzite ; by R. C. WEILS	636
LVI.—On the Crystallization of Willemite ; by C. PALACHE and R. P. D. GRAHAM	639

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Action of Sulphur Trioxide upon Salts, W. TRAUBE, 644.—Volumetric Determination of Fluorine, A. GREEF: Behavior of Hydrogen towards Palladium, GUTBIER, GEBHARDT, and OTTENSTEIN: A New Era in Chemistry, H. C. JONES, 645.—Experiments Arranged for Students in General Chemistry, E. F. SMITH and H. F. KELLER: Chemical German, F. C. PHILLIPS: Spectrum of the Aurora Borealis, L. VEGARD, 646.—To Produce a Continuous Spectrum in the Ultra-violet, V. HENRI: The Gyroscope, F. J. B. CORDEIRO, 647.—Medizinische Physik, O. FISCHER: Wonders of Wireless Telegraphy, J. A. FLEMING, 648.—Principles and Methods of Geometrical Optics, Second Edition, J. P. C. SOUTHALL: Physical Measurements, A. W. DUFF and A. W. EWELL: Über kausale und konditionale Weltanschauung und deren Stellung zur Entwicklungsmechanik, W. ROUX, 649.—Annals of the Astrophysical Observatory of the Smithsonian Institution, 650.

Geology and Mineralogy—Research in China, 650.—Fosseis Devonianos do Paraná, 652.—Monograph of the Terrestrial Palæozoic Arachnida of North America, 653.—The Heart of Gaspé; Sketches in the Gulf of St. Lawrence: Ninth Report of the Director of the Science Division, 654.—New Trilobites from the Maquoketa Beds of Fayette County, Iowa: New Paleontologic Periodical—Palæontologische Zeitschrift: Petrology of the alkali-granites and porphyries of Quincy and the Blue Hills, Mass., 655.—Geology and Ore Deposits of the Philipsburg Quadrangle, Montana: Gems and Precious Stones in 1912, 656.

Miscellaneous Scientific Intelligence—National Antarctic Expedition, 1901-1904; Meteorology, Part II, 656.—Annual Report of the Board of Regents of the Smithsonian Institution, showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1912: Report on the Progress and Condition of the U. S. National Museum for the year ending June 30, 1912, 657.—Publications of the British Museum of Natural History: Publications of the Museum of the Brooklyn Institute of Arts and Sciences: National Academy of Sciences, 658.—Elements of Bacteriological Technique, 659.

Obituary—A. R. WALLACE: W. H. PREECE, 659.

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE,
W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS,
LOUIS V. PIRSSON, HERBERT E. GREGORY
AND HORACE S. UHLER, OF NEW HAVEN,

PROFESSOR HENRY S. WILLIAMS, OF ITHACA,
PROFESSOR JOSEPH S. AMES, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

No. 211—JULY, 1913.

NEW HAVEN, CONNECTICUT.

1913.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. \$6.40 to countries in the Postal Union; \$6.25 to Canada. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).

NEW DISCOVERIES AND NEW FINDS.

BEAVERITE, A NEW MINERAL.

This mineral, which was fully described in the December, 1911, number of this Journal, I have been fortunate enough to secure the whole output of. It was found at the Horn Silver Mine in Utah and is a hydrous sulphate of copper, lead and ferric iron. It was found at a depth of 1600 feet. In appearance it resembles Carnotite. Prices 75¢ to \$2.00.

PSEUDOMORPHS OF LIMONITE AFTER MARCASITE.

These remarkable Pseudomorphs, which have never before been found in such clear cut specimens, was described and illustrated in the last number of this Journal. I have secured the majority of the finest of these specimens. They vary in size from 2 inches to 6 inches. In color they run from brown to glossy black and they have met with favor from all who have seen them. Prices from \$1.00 to \$10.00.

CHIASTOLITES.

Of these remarkable specimens, which are generally known as lucky stones, I have secured the finest lot ever found at Madera Co., California. They are cut and polished and sold singly and in collections from 25¢ to 50¢ for single specimens; 9 specimens all marked differently for \$5.00, and 18 specimens, all different markings, for \$18.00. Matrix specimens, polished on one side showing many crystals, from \$2.00 to \$8.00.

SYNTHETIC GEMS.

It is remarkable the interest that has been taken by scientists in these wonderful scientific discoveries. The Corundums are now produced in Pigeon blood, Blue, Yellow, Pink and White. Also the new Indestructible Pearls in strings with gold clasps. These are identical in hardness and rival in color and lustre the real gems. They can be dropped and stepped on without injury and are not affected by acids. My collection of the above is unrivalled, and prices of the same are remarkably low.

OTHER INTERESTING DISCOVERIES AND NEW FINDS

Will be found in our new Catalogues. These consist of a Mineral Catalogue of 28 pages; a Catalogue of California Minerals with fine Colored Plates; a Gem Catalogue of 12 pages, with illustrations, and other pamphlets and lists. These will be sent free of charge on application.

Do not delay in sending for these catalogues, which will enable you to secure minerals, gems, etc., at prices about one-half what they can be secured for elsewhere.

ALBERT H. PETEREIT

261 West 71st St., New York City.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. I.—*The Investigation of the Prehistoric Human Remains found near Cuzco, Peru, in 1911*; by HIRAM BINGHAM.*

IN the American Journal of Science for April, 1912, the present writer made a brief report on "The Discovery of Prehistoric Human Remains near Cuzco, Peru." Published in connection with this report was a paper by Prof. Isaiah Bowman on the "Geologic Relations of the Cuzco Remains," and another paper by Dr. G. F. Eaton, entitled: "Report on the Remains of Man and of Lower Animals from the Vicinity of Cuzco, Peru."

It will be remembered that a small collection of vertebrate remains had been found interstratified with the gravel bank in the Ayahuaycco Quebrada, not far from Cuzco; and that these bones were brought to New Haven for study.

It was a keen disappointment to us that we were not able in 1911 to spend more time in Cuzco. I concluded my report as follows: "Notwithstanding my great interest in these prehistoric human remains, I felt it was wiser to carry out the plans originally adopted for the Expedition, although that meant a hurried departure from Cuzco without doing more than is shown by the results presented herewith. It seems to me extremely desirable to continue the work of exploration and excavation in and about Cuzco, for it is highly probable that important data bearing on Inca and pre-Inca civilization may be obtained here."†

Chiefly owing to the interest shown in this discovery, and in others made on the same expedition, by the National Geographic Society and by certain friends of Yale University, it was possible to return to Peru in 1912 and make a thorough

* Director of the Peruvian Expedition of 1912.

† This Journal (4), xxxiii, p. 305.

investigation of the Ayahuaycco Quebrada and of the Cuzco Valley.

The Expedition of 1912 reached Cuzco in June and left at the end of November. Nearly three months were spent in a careful topographic survey of the Cuzco Valley. A portion of that map is published at this time. The remainder will appear in connection with the complete geological report of the Expedition.

Remembering that I had seen many bones in position in various parts of the vicinity, and feeling that it would be entirely impracticable to bring home all this bone material without knowing its value, I persuaded Dr. Eaton, who had reported on the bones brought home in 1911, to accompany the Peruvian Expedition of 1912 in the capacity of osteologist. The approved plan for his work included: (a) a careful search for bone deposits in the cliffs of the Ayahuaycco Quebrada and in other similar cliffs in the vicinity wherever located within easy reach of trails; (b) search for bone deposits at heights not easily accessible from trails,—such deposits rarely coming within the category of human burials, and such search requiring the use of rope slings; (c) especial attention to be paid to the occurrence of remains of pre-Hispanic and Hispanic animals, including domestic poultry, horses, asses, mules and cattle; (d) examination of skeletons of contemporary bovines, to determine the value of the peculiar characteristics noted in the fragmentary bovine rib found in 1911; and, (e) an examination of the so-called “Cuzco ash-deposits,” to determine their origin and true character.

It also seemed to me that it was essential to have a geologist make a far more comprehensive study of the geology of the Cuzco Basin than had been possible in the few days at Prof. Bowman's disposal in 1911. Moreover it seemed advisable that these geological studies should be made by an independent and impartial observer, who should be in no wise influenced by any necessity for substantiating the previous findings, nor by any desire to discredit them. As the previous work had been done by a Yale man, it seemed to me most appropriate that the proposed studies should also be done by a member of the same Faculty, and I accordingly considered myself most fortunate in being able to persuade Prof. Herbert E. Gregory, Silliman Professor of Geology in Yale University, to accept the commission of Geologist of the 1912 Expedition, and to go to Cuzco and make a special study of the Cuzco gravels. His report on this subject and Dr. Eaton's on the vertebrate remains which he found in the Cuzco gravels are presented herewith. While the results are not as exciting as some people wish they were, it is a great satisfaction to me to have been able to get to the bottom of this interesting problem.

ART. II.—*Vertebrate Remains in the Cuzco Gravels*; by
GEORGE F. EATON.*

THE Yale Peruvian Expedition of 1911 collected human remains in the Ayahuaycco Quebrada of Cuzco, Peru, under conditions that called for a more critical investigation than was possible at the time of the discovery. So much interest attaches to the question of the existence of Man during the Glacial Period of geological time that it seemed desirable to make every effort to obtain some decisive evidence regarding the antiquity of the fragmentary remains popularly known as the Cuzco Man. Accordingly the plans for osteological work by the expedition of 1912 not only provided for a general search for bone deposits in the alluvium of the Cuzco Valley, but also included a special study of the gravels of the Ayahuaycco Quebrada.

It will be recalled by those who read the preliminary reports on this subject† that neither the geological evidence nor that derived from a strictly osteological study of the bones themselves was to be relied on in determining the age of the deposit, only the barest indications of great antiquity being observed in the remarkably bisonic form of a bovine rib associated with the human bones. Had it been possible to identify this rib positively as that of an extinct species of Bison, a claim to great antiquity for the "Cuzco Man" would have been almost unassailable; but believing that the premises did not warrant such a conclusion, I made the following statement in the preliminary report on the bones: "It cannot be denied that the material examined suggests the possibility that some species of Bison is here represented, yet it would hardly be in accordance with conservative methods to differentiate Bison from domestic cattle solely by characters obtained from a study of the 1st ribs of a small number of individuals."

From what I was able to learn of the beef industry in and about Cuzco, practically all the beeves slaughtered for the Cuzco trade are raised on the elevated pastures within one day's drive of that city; and one of the first steps taken toward solving the problem under consideration, after the arrival of the expedition at Cuzco, was to examine the first ribs of carcasses of beef animals offered for sale in the public markets. This convinced me that under the life-conditions prevailing in this part of the Andes, and possibly in correlation with the increased action of the respiratory muscles in the rarefied air, domestic cattle occasionally develop 1st ribs closely approaching the form observed in Bison. Therefore, apart from purely geological

* Osteologist of the Peruvian Expedition of 1912.

† This Journal (4), xxxiii, p. 332, April, 1912.

considerations, no reason remains for supposing that the bovine rib, found with the human bones in the Ayahuaycco Quebrada in 1911, belonged to a Bison; and any theory attributing great antiquity to the "Cuzco Man," based on such a supposition, is rendered untenable.

When preparing my contribution to the preliminary report of the Expedition of 1911, I preferred to limit myself to a strictly osteological discussion of the material submitted to me, without any recourse to the geological relations of the discovery. Now that I have visited the locality where the material was collected, the problem may be treated more broadly, and utilized as fully as possible in connection with the further study of the bone-deposits of the region.

In June, 1912, the shallow excavation, made in the north-east wall of the Ayahuaycco Quebrada by the Expedition of 1911, was revisited. It was apparently just as it had been left eleven months before. Not even had the little mound of gravel, thrown out by the excavators, been washed away from the side of the trail by the showers of the past rainy season. The original collectors had done their work so carefully and completely that nothing recognizable was to be found, by sifting this fallen material, except a sternal segment, referable to *Canis* sp., and a fragment of the labial cusp of a human upper premolar. These two small specimens probably belong with the bones taken out in 1911. They have little significance beyond making it appear likely that the human and canine remains, deposited in this place, were slightly more complete than they were, at first, reported to be, and to that extent more suggestive of the ancient burial customs of the region.

The coarse gravel immediately surrounding the excavation of 1911 was compact and free from cracks or flaws. It had, in fact, every appearance of being an undisturbed integral part of the flat-topped gravel spur that separates the Ayahuaycco and Huatanay Quebradas. To make sure that there was no lack of homogeneity in the gravel at this place it was proposed that a small tunnel, commencing at the excavation of 1911, should be made directly into the face of the cliff. This was accordingly done at a time when Professor H. E. Gregory, the geologist of the expedition, could visit the scene. During the first day's work I encountered no cracks or fissures in the gravel, and Mr. K. C. Heald, who continued the tunneling, reported that the gravel cut through by him was everywhere extremely firm and without break of any kind. The solidity and firmness of the formation are attested by the fact that, in three days' time, our laborers were able to penetrate only 11 feet into the cliff, the height and width of the tunnel being $4\frac{1}{2}$ feet and 3 feet respectively. The gravel exposed within the tunnel was of precisely the same character as the gravel of the cliff about the entrance.

If this tunnel with carefully shaped parallel sides had cut through a contact between the basal mass of gravel and an overlying "veneer," deposited by landslide against its face, some indication, no matter how slight, of the lack of continuity should have been presented. As the tunnel offered a much better opportunity for recognizing a possible break in the gravel than the original excavation offered, I am led to suppose that, if in either period of work at this place, a contact between basal mass and gravel of later deposition was reached, it was not during the tunneling, but in 1911 during the first period of excavation.

At the time when the bones were excavated Professor Bowman was fully aware of the significance such a break would have in determining their age; and the following quotation from his report shows that he actually encountered what, at first view, looked very much like an extensive break in the gravel enclosing the bones:

"Immediately above the stratum containing the bones was a break in the face of the bluff about four feet long. It rose in a curved line about two feet above the layer in which the bones were disposed and suggested the upper part of a grave, especially as the break exhibited a mould of organic material. After the excavation work was done, as much care was exercised in the examination of this break as in the gathering of the bones. Upon excavation of the gravel along the line of the break and forward from it two facts were discovered: (1) the break extended downward but a few inches and merged into hard undisturbed material in which the bedding planes ran apparently without interruption from within the main gravel mass to the outer edge of the bluff; (2) the mould consisted principally of a fungus growth mixed with a few species of lichens."*

It is difficult to advance and maintain any theory at variance with the foregoing careful statement by Professor Bowman regarding the apparent condition of the gravel surrounding the bones; and yet, after studying the form and composition of the walls of the quebrada and examining other deposits of bones both here and elsewhere in the Province of Cuzco, I am led to the opinion that the bones excavated in 1911 were not originally embedded in the basal gravel of the spur at the time when that gravel was itself in process of deposition, but were, in all probability, interred there at a much later time when the northeast wall of the quebrada had assumed more nearly its present contours.

The upper part of the Ayahuaycco Quebrada is shown in the accompanying view (fig. 1), taken from the southwest side

* This Journal, l. c., p. 310.

and looking northerly. The point of the arrow marks the place of the excavation of 1911. The view shows also the flat top of the gravel spur, separating the Ayahuayeco and

FIG. 1.

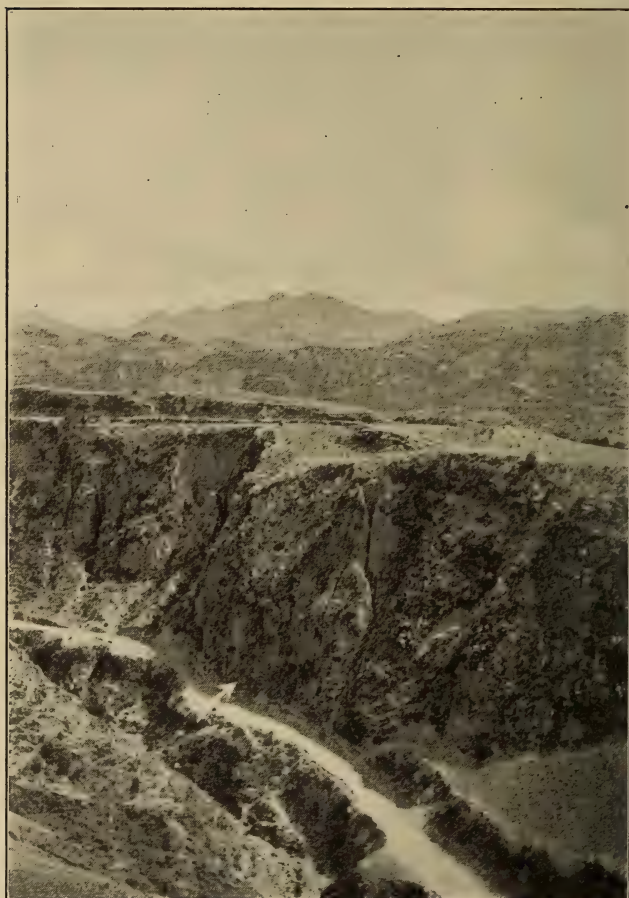


FIG. 1. View of the northeast side of the Ayahuayeco Quebrada, taken from the opposite cliff. The point of the arrow marks the site of the excavation of 1911.

Huatanay Quebradas, and certain other features to which I wish to refer. The general course of the upper part of the quebrada is about N. W. and S. E. In the down-stream direction (S. E.) from the excavation of 1911, a cultivated terrace extends along the foot of the cliff for several hundred feet.

It narrows gradually as it approaches the place of excavation, until it finally ends about 10 feet from this place. In the photograph the foot of the cliff lies in such deep shadow that the extreme prolongation of this terrace is not visible. The terrace appears to be composed, almost entirely, of material that has fallen from above. In the opposite direction (N. W.) from the place of excavation, and about 60 feet distant from it, is a somewhat confused mass of talus material. As this is separated from the previously described terrace by a gap of only about 70 feet, it is quite possible that these two masses of fallen gravel may have been connected, at some earlier time, by an intermediate portion that has been cut away during recent improvement and widening of the road. In fact the general character of that part of the slope lying between the road and the brook-bed, at the bottom of the quebrada, makes this seem probable. Whether these masses of talus were continuous or not, there must have been, from time to time, considerable quantities of gravel falling from the top and face of the cliff over the place where the bones were found.

The diagrams, arranged under fig. 2, represent three possible stages of development at the foot of the quebrada wall where the excavation was made. A grave containing human remains may have been left open in the face of the gravel cliff, as indicated in Section I. This seems to have been one form of burial practiced by the Indians of the region. Many open graves of this character were observed in the face of a steep gravel bank in the neighborhood of Urubamba, one day's ride from Cuzco; and it is interesting to note that none of these graves that I was able to examine contained entire skeletons, merely disarticulated or fragmentary bones. Section II shows the result of an enlargement of the talus. Gravel deposited at this point would fill the open grave, and would closely simulate the basal gravel of the cliff. The filling would, however, tend to be somewhat less compact at the top of the grave than at the bottom, and a shallow "break" might develop under the roof of the grave when the filling had settled. In section III the trail, known as the lower road to Anta, has been improved and widened by removing a considerable quantity of gravel from the talus and also from the face of the cliff. At this stage the inner portion only of the grave is left; and the greater part of its original contents, already broken and displaced by decay and by the impact of the falling gravel, if not by inquisitive and ceremonial visitors, has been cut away by the mattocks of the road-menders.

The foregoing explanation of the occurrence of vertebrate remains at this place in the quebrada would apply to almost any time during the three centuries and a half that have elapsed since the Spaniards brought domestic cattle to Peru;

but it would not otherwise fix the date when the bones were deposited here. Their exact age cannot be determined.

In regard to the bones of lower animals accompanying these human remains: it seems to have been an ancient and common practice, in this part of Peru, to place in the human grave, pieces of the flesh of llamas, and occasionally, if the mute

FIG. 2.

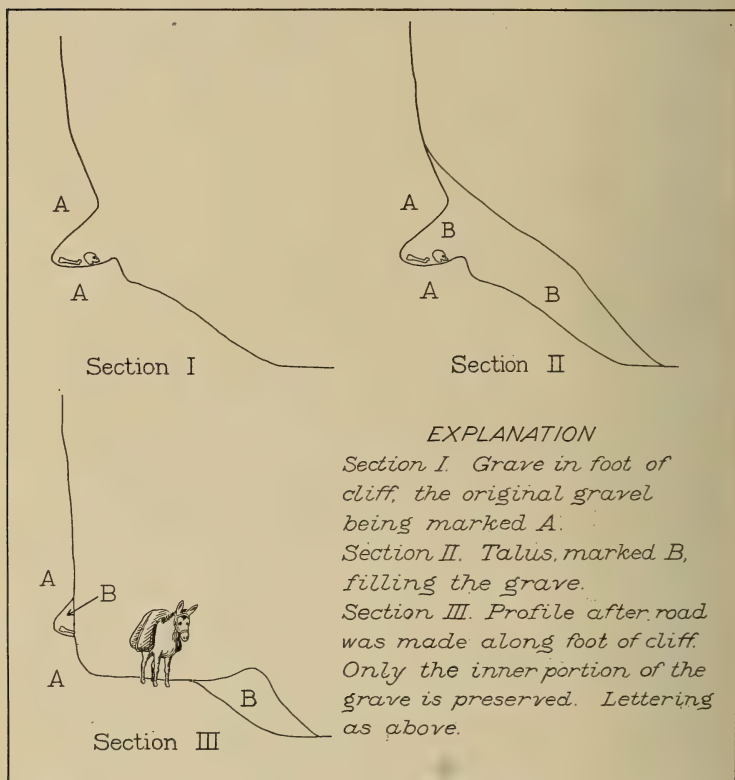


FIG. 2. Diagrams showing possible changes in the profile of the foot of the cliff where bones were excavated in 1911.

testimony of the bones can be relied on, a dog's entire carcass. There is no reason to suppose that this ancestral custom would have been discontinued until long after the introduction of European domestic animals; and accordingly there should be nothing surprising in the occurrence of beef bones in human graves, either with or without bones of the native animals.

I shall have occasion, a little further on in this paper, to describe a grave where horse bones were interred with the human remains.

Further search along the walls of the quebrada was rewarded by the discovery of several other bone deposits whose history seems to have been almost as closely connected with recent changes in the contours of the gravels as was the history of the deposit found in 1911. Reference has been made to a mass of talus material at the foot of the northeast wall and about 60 feet distant from the excavation of 1911. In this

FIG. 3.



FIG. 3. Near view of a portion of the talus 60 feet N. W. from the excavation of 1911. The upturned point of the pick marks the site of a grave.

material, by the side of the trail, human bones were found under conditions differing from those that obtained in the interment previously described. Figure 3 is from a photograph of the cut bank where these bones were found, the position of pieces exposed at the surface being marked by the upturned point of the pick. Excavation at this place brought to light parts of two human skeletons, a fragment of a llama's vertebra, a piece of charred bone, a few podial bones of some small unidentified mammal, bits of charcoal, and a small flat piece of bone, about $1\frac{1}{2}$ inches long and $\frac{1}{2}$ inch wide, pierced at one end. No pottery was found. The human material shows no departure from the modern Indian type of the region, and possesses little morphological interest except that the iliac portion of a left os innominatum has no preauricular sulcus, while the same portions of two smaller and slighter ossa innominata,

right and left, present very deep and well-defined sulci, and are therefore recognized as female. Of the two human individuals, the larger, supposed to be male, was represented by the following bones: a series of ten dorsal and lumbar vertebræ in nearly perfect articulation with each other and with the sacrum, the left ilium still in contact with the sacrum, the distal two-thirds of the left femur, the proximal part of the left tibia, the left fibula in two fragments, the distal half of the right humerus, and a few more or less fragmentary ribs. The smaller individual, female, was represented by only a few bones, namely: the first sacral vertebra, the left ilium, and the articular portion of the right, the left humerus, and the left radius. There were also an incisor tooth, a coccygial vertebra,

FIG. 4.

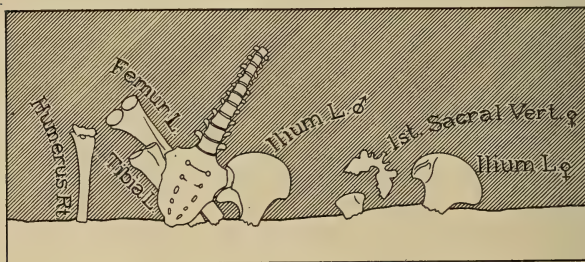


FIG. 4. Horizontal arrangement of bones at the face of the talus in the place shown in fig. 3.

a patella, and a few podial bones that may belong to either individual. No other human bones were found at this place although the gravel surrounding the bones was excavated freely in the hope of finding more. The position of some of the principal bones, relative to the face of the cut bank, is shown in fig. 4. The series of dorsal, lumbar and sacral vertebræ lay in a nearly horizontal plane with the ventral surfaces uppermost. The unnatural position of the left femur and tibia underneath the pelvis, and the absence of the skull and anterior vertebræ, while the rest of the vertebral column is so well preserved, are conditions not likely to occur in an undisturbed grave. Although some of the bones may have been removed with gravel cut away by the road-menders, this would not explain the peculiar disarrangement of the rest. The conditions described can best be accounted for on the supposition that the original interment was made higher up on the cliff—perhaps at the top—and that subsequently, when one of the small landslips that have built up the talus occurred, the contents of the grave were dislodged and carried down to the foot

of the cliff in such a manner that only a part of the original skeletal material was preserved intact.

The cultivated terrace extending along the foot of the north-east wall of the quebrada appears to be composed largely of gravel fallen from the cliff. Scattered irregularly through this terrace, and exposed to view by the roadside, were potsherds and fragmentary bones, mostly of llamas, but with an occasional beef- or dog-bone. As these specimens resembled the pottery and fragmentary bones that were found, strewn to a depth of a few inches, in the flat top of the gravel spur, they may have been derived principally from the latter elevation. There was, however, one small area, exposed in section at the face of the terrace, that showed some of the characteristics of a kitchen-midden. It was a stratum of gravel having a large admixture of charcoal and wood-ashes. Potsherds and bones occurred more plentifully here than elsewhere in the terrace. This stratum had a maximum depth of about 18 inches, and could be traced along the face of the terrace, a little above the level of the roadway, for a distance of about 30 feet. Fig. 5 shows a portion of the stratum, though not as clearly as could be desired. From its size and shape and from the general character of its contents this stratum appears to be a midden built upon the talus slope by the accumulation of miscellaneous débris during some period since the Conquest when little or no gravel was falling from the cliff. Undecorated potsherds, too small to convey any definite idea of complete form, were found here together with fragmentary bones of llama, dog, domestic cattle and deer, and also bits of charred bone and a copper or bronze needle. This last is an interesting relic. It is a round needle $4\frac{3}{4}$ inches long, and a trifle less than $\frac{1}{8}$ inch in diameter. The eye has been formed by piercing the blunt end, instead of by drawing out the metal and bending it around in the more primitive way sometimes followed.

The great quantity of llama bones buried in the Ayahuaycco Quebrada and in other places near Cuzco indicate that after the subjugation of the Cuzco region by the Spaniards, the flesh of the llama still formed the larger part of the meat diet of the natives, and was accordingly considered the most suitable, or the most convenient, kind of flesh that could be provided for the supposed needs of the human dead after interment. When domestic cattle became commoner in the region their flesh naturally replaced that of the llama, to some extent, as an article of food for the living Indians, and as a provision for the dead, but I have not yet met with or heard of any instance of the modern Indians of the region eating the flesh of horses or mules.

I have already alluded to a grave containing horse bones. It was located at the foot of the cliff forming the southwest boundary of the quebrada, and was nearly opposite the lower

FIG. 5.

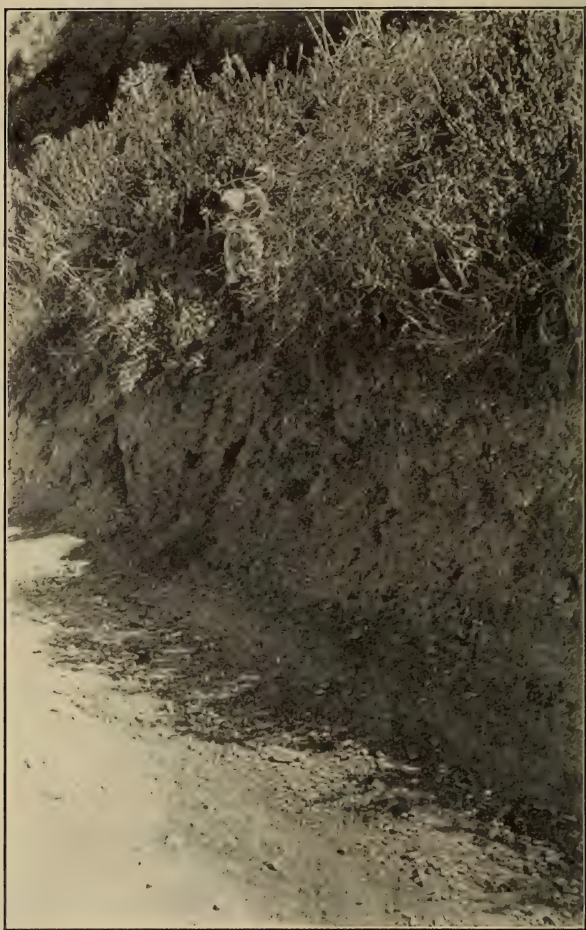


FIG. 5. View of a portion of the face of the long terrace where a section of a kitchen-midden was exposed.

end of the long cultivated terrace. A peculiar circumstance was the position of the grave in an immense block of alluvium, composed of strata of coarse and of fine material, that had

slipped bodily down the face of the cliff from a height of about 30 feet, without being overturned or entirely disintegrated. The block of alluvium is shown in fig. 6, the hand

FIG. 6.

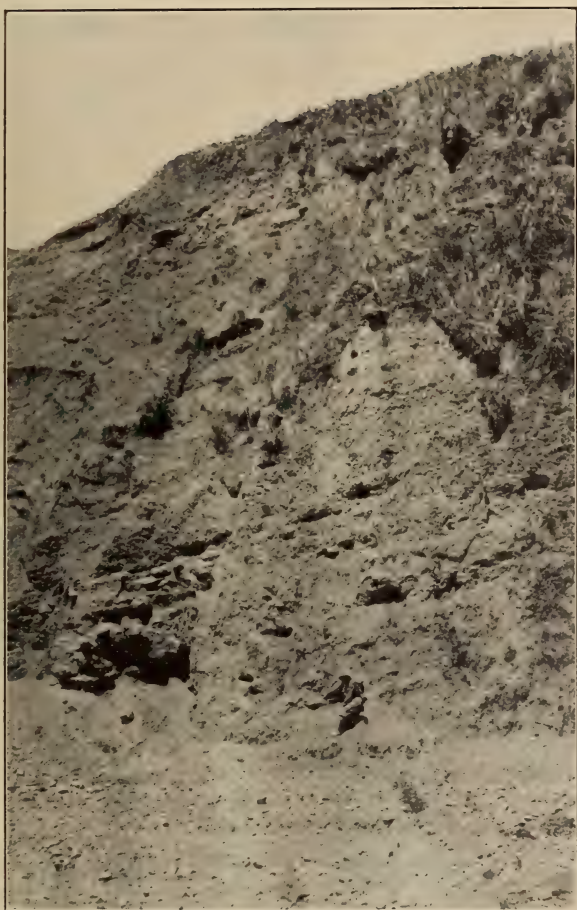


FIG. 6. Location of a grave in a fallen block of alluvium. Southwest cliff of Ayahuaycco Quebrada. The man's hand marks the position of the grave.

of the man in the view marking the place where the bones lay buried in a stratum of fine material. Most of the bones excavated at this place were fragmentary and in a poor state of

preservation. Portions of six human femora were obtained—showing that no less than three individuals had been buried together. A fragmentary skull was found impaled on the distal end of a femur, the base of the skull being fractured so as to admit the end of the long bone within the brain-chamber. This may have resulted from the compression of the alluvium by the landslip, if the body represented by these two bones was interred in the conventional sitting position with raised knees. Among the other human skeletal parts found here were the left parietal of a second skull, a few crumbling vertebræ, a pair of innominate bones (male), four tibiæ, three fibulæ, and several podials. Besides the human remains and a few llama bones, the grave contained the upper portions of a horse's tibia and radius. As these equine bones were associated with human remains in the same way that bones of llama and ox were, in the grave excavated in 1911, and that llama bones alone were in many graves in other parts of the Inca empire, there can be little doubt that they, or more correctly the flesh attached to them, were also intended to serve as a provision for the supposed needs of the dead. Whether such a use of horse-flesh fully satisfied the local conventions regarding human burial, remains a matter of surmise.

Ruined graves were found in two other places in the walls of the quebrada. Their contents were extremely meager, and beyond adding to the total number of graves observed, they were of no special interest. Local traditions, in Peru, are not always reliable, but the meaning of the name Ayahuayeco "valley of the dead"—and the tradition, recorded by Professor Bingham,* that it was once used as a burial place for plague victims, seem very appropriate.

Near the lower end of the quebrada three more middens were observed. Two of them were still being built up with the unsightly debris of the neighboring part of the city. The third was on the right bank near the stone water-tank. Overlain by the gravel wash of the stream, or of the adjacent slope, it had an appearance of pseudo-antiquity; but after a brief examination, bones of domestic animals of European origin were found in the lower part of the deposit, showing that although this midden may be considerably older than the two others, it belongs to the modern city, and does not date from pre-Hispanic times. Where the middens of the early Inca city are located, and what interesting relics they may contain, are problems that will perhaps not be solved until the government permits extensive work of excavation in the public plazas, and the owners of modern houses, built upon ancient ruins, are persuaded to take a livelier interest in Peruvian archeology than they do at the present time.

* This Journal, 1. c., p. 302.

ART. III.—*The Gravels at Cuzco, Peru*; by HERBERT E. GREGORY.*

Introduction.—A prominent feature of the Cuzco Valley is a fringe of unconsolidated deposits exhibited as walls or dissected slopes. With the exception of a superficial cover of recent sediments these border forms are the remnants of piedmont alluvial deposits which date from a time when waste prepared through a long period of local disintegration was stripped from the highlands and carried to the central valley below. The bulk of these deposits is assigned to the late Pleistocene on the basis of the interlocking relations which the gravels flanking the lower slopes sustain to the slightly modified glacial drift now occupying the valley heads.

The most extensive of these Pleistocene fluvial deposits and those best exposed for study are the fans which mark the mouths of nearly all valleys, even minor ravines and wet-weather channels, which enter the Cuzco basin. Two of these fans, San Gerónimo and Cuzco, the former actively aggrading, the latter in a stage of rapid disintegration, are conspicuous among the gravel accumulations of the Cuzco Valley, and are somewhat unusual, both in extent and in thickness, as border features of a valley of such limited dimensions.

The Cuzco fan, while presenting no essential features which differentiate it from other examples of its class, is deemed worthy of somewhat extended description in view of twofacts: (1) the city of Cuzco is built on the outer dissected fringe and the terminal bluffs of the fan—a city which probably marks the site of one of the earliest permanent human settlements on the South American continent. (2) Because these gravels have yielded implements, pottery, the bones of lower animals, and human bones, which on the basis of a preliminary examination were tentatively assumed to date from glacial times.†

Topography.—In superficial extent the Cuzco gravels are arranged as a wide-open V or triangle whose apex extends to the divide separating the Anta and the Cuzco basins and whose base forms a curved line reaching from the Chunchullumayo Quebrada, where it merges with a second fan, to the limestone bluffs one mile due north of the railroad station. (See map, fig. 2.) In topographic expression it consists of two parts: the lower portion on which the city is built is bounded on the north and northwest by steep-faced bluffs; on the south and west it grades imperceptibly into the main valley floor.

* Geologist of the Peruvian Expedition, 1912.

† Bingham: *The Discovery of Prehistoric Human Remains near Cuzco, Peru*; and Bowman: *The Geologic Relations of the Cuzco Remains*. This Journal, vol. xxxiii, pp. 297-325, 1912.

FIG. 1.



FIG. 1. View of the upper portion of the Cuzco valley showing the surface topography of a portion of the Cuzco gravels. The valley in the right foreground is the Ayahuaycco Quebrada ; the Rio Suppi occupies the steep-walled trench in the left foreground. Photograph by Hiram Bingham.

FIG. 2.



FIG. 2. Map of the Cuzco gravels, showing present distribution (light shading) and supposed former extent (dotted line), also areas of bed rock (heavy shading). Topography by the Peruvian Expeditions of 1911 and 1912.

Its slope is 200' per mile and its surface is diversified by flattened hills much reduced by grading, valley filling, and canalization of streams, processes which have been going on since Inca days. The upper portion of the fan (fig. 1) is a nearly level plateau, deeply trenched by the Ayahuaycco Quebrada,* and by gravel-walled canyons tributary to the Huatanay.† The Ayahuaycco ravine reaches a depth exceeding 140'. Its northeast wall, cut entirely in gravels and sands, presents slopes of 20° to 60° which increase to 60° to 80° at the base (see fig. 1, p. 6; fig. 6, p. 13); its southwest wall is of gentler slope, and consists in part of bed rock. The five western tributaries of the Huatanay are sharply cut gravel canyons ending in box heads,—the southernmost one, leading to a flat 240' above the river, is confined between banks with an average slope of 70°, and at one point presents a vertical wall 110' high. In fact at certain points in these canyons the walls are undercut ten to fifteen feet without, however, interfering with the stability of the compact gravel mass. Such canyon faces, built entirely of coarse unconsolidated sediments, are made possible by the distribution of calcareous cement among the finer constituents, and by exceptional conditions controlling ground water circulation. To reach the upper gravel flats from the city requires an ascent of 400'.

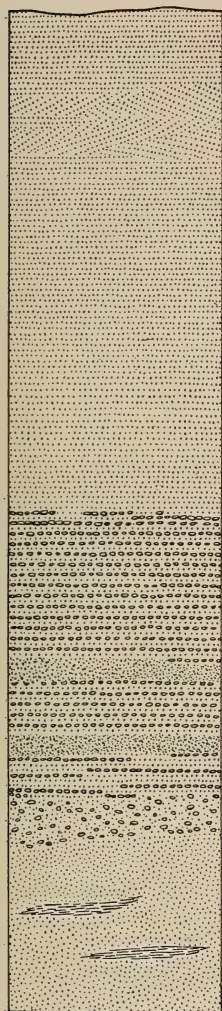
Throughout the entire area covered by the fan gravels, rock is exposed only in the bed of the Huatanay and at a few places in the Ayahuaycco and its tributaries. (See map, fig. 2.)

Structure.—Speaking broadly, the Cuzco fan is built of thick, widespread deposits of gravel within which are included lenses of fine sand. Most of the gravels are very coarse, approximately one-half of their bulk consisting of pebbles exceeding an inch in diameter. Stratification in the gravels is nowhere well developed, but may be detected in large exposures by the relatively high per cent of flattened pebbles which tend to assume horizontal positions. However, many portions of the quebrada walls 1000–2000 square feet in area appear equally well stratified vertically and horizontally and a photograph of such banks reveals essentially the same structure regardless of the position from which it is viewed. (See p. 1, fig. 6.) In fact the difference between the unmodified fan deposits composed exclusively of gravel and the slides, artificial gravel heaps, or the bouldery floor of the present torrential streams is to be detected only by the closest scrutiny. In brief a large part of the materials of the fan constitute a heap of unassorted

* Quebrada is a Spanish-American term applied to narrow steep-walled water courses regardless of dimensions. As used locally the term includes both arroyos and canyon. Ayahuaycco signifies, "Valley of the Dead."

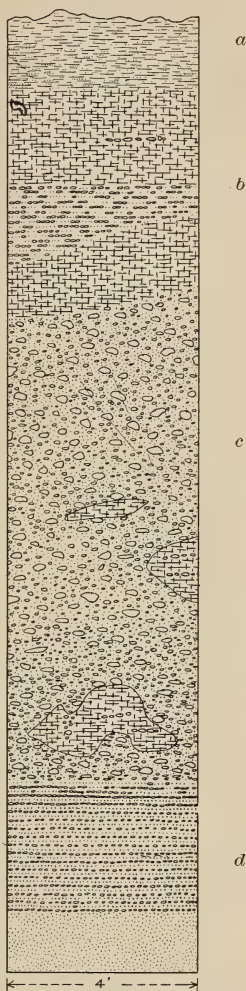
† The Huatanay consists of the Rio Sappi and its affluents.

FIG. 3.



- a*, 14 ft., horizontally bedded sand with slight cross-bedding.
b, 4 ft., gravel and sand interbedded.
c, $\frac{1}{2}$ ft., fine sand cemented.
d, $1\frac{1}{2}$ ft., gravel and sand interbedded.
e, fine sand cemented.
f, sand with stringers of gravel.
g, coarse gravel.
h, 5 ft., sand with two clay lenses.

FIG. 4.



- a*, soil and debris.
b, 4 ft., adobe with lenses and stringers of gravel.
c, 10 ft., coarse gravel with masses of adobe.
d, 4 ft., sand with thin-gravel beds in upper part.

FIG. 3. Section II, west bank of Ayahuaycco Quebrada at mouth of canyon portion of valley. Dip S. W. \angle 2° .

FIG. 4. Section III, Ayahuaycco Quebrada, 200 feet from mouth. Note absence of gradation between strata. Boulders six to eight inches in diameter rest directly upon the smoothed surface of adobe. Gravels traverse adobe masses vertically and horizontally.

boulders of various sizes between which finer materials have been irregularly deposited. The sand beds consist of fine well-washed quartz grains which in places are bound together by films of calcareous mud. Through the body of the fan the sand is displayed as lenses rarely exceeding 2' in thickness, and usually dying out laterally within a distance of 100'. The largest bed observed is six feet in thickness and extends for about 225'. Near the upper surface of the fan the sand lenses are more abundant and have a somewhat wider extent; at one point constituting nearly $1/5$ of the material exposed.

At the outer edge of the fan where its deposits interleave with silts and calcareous muds of an ancient water body, sands and adobe assume the leading rôle, the gravels playing a minor part. There is here also a much more frequent alternation of beds and a much greater change in short horizontal distances.

FIG. 5.



Fig. 5. Section IV, Detail of gravel shown in section III; size and orientation of pebbles drawn to scale.

The stratified phases of the Cuzco gravels slope in general southward at various degrees of inclination. At the mouth of the canyon portion of the Ayahuaycco the well-stratified beds of sand included within the gravel mass dip south at an angle of 3° – 5° . At the edge of the bluffs facing the city and on the slope northwest of Santa Ana church dips of 8° – 10° south were measured, while the strata which cap the deposits along the Anta road are practically horizontal. Cross-bedding though present is not a conspicuous feature, doubtless being obscured by the prevailing unstratified condition of the gravels, but cut and fill channels trending in various directions are revealed in nearly every section.

The accompanying sections (sec. I and figs. 3–9) illustrate the structure and arrangement of beds in selected portions of the delta.

Section I. Mouth of Ayahuaycco Quebrada.

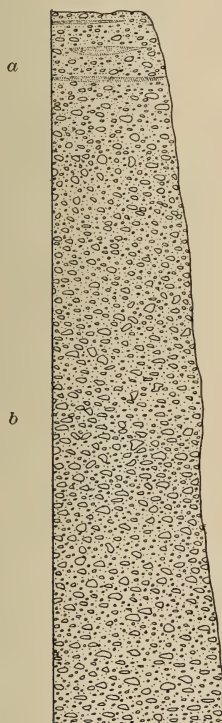
Dip 4° south.

	Feet
1. Soil, red-brown, sandy, with bands of brown adobe, streaked with calcareous bands and penetrated by root tubes	10
2. Gravel, composed of subangular pebbles 1 to 6 inches in diameter, of brown and grey sandstone, rarely limestone; partially cemented by calcareous films. Bottom rests unconformably on the channeled surface of No. 3	4

- | | Feet |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 3. Sand, coarse, mingled with clay-adobe, firmly cemented with lime; dull yellow on weathered surfaces, brown and white beneath ----- | 3 |
| 4. Gravel, composed of flattened subangular pebbles of grey and brown sandstone, 1 to 6 inches in length. Many pebbles partially decomposed. Contains irregular lenses of coarse sand. ----- | 5 |

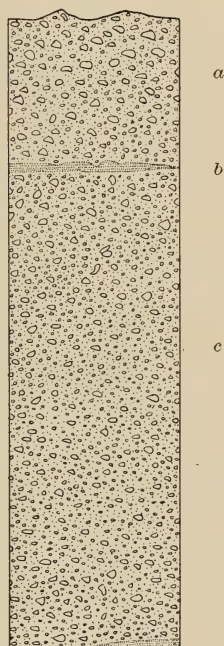
For Sections II-VIII see accompanying figures.

FIG. 6.



a, 30 ft., coarse gravel, with lenses of sand.
b, 120 ft., coarse gravel, massive.

FIG. 7.



a, 15 ft., very coarse gravel.
b, 1 ft., fine sand, stratified.
c, 50 ft., very coarse gravel, massive.

FIG. 6. Section V, North bank of Rio Sappi at mouth of tributary descending from the Cuzco-Anta divide.

FIG. 7. Section VI, Bank of tributary to Rio Sappi, descending from the Cuzco-Anta divide.

Composition. Source of Material.

The highlands which contributed material to the Cuzco fan consist, on the northeast, of grey-blue limestone through which protrude small knobs of greenish igneous rock (altered diabase)

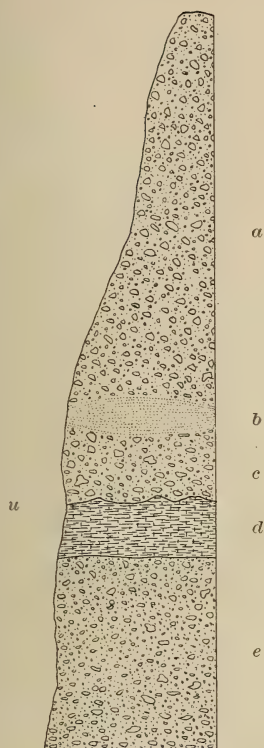
along the Huatanay and on the Anta divide. The contributory area on the west and northwest is underlaid by brown and grey sandstone, chiefly the former. Sandstone furnished the bulk of the material, and in the Ayahuaycco Quebrada fully 95 per cent of the pebbles have this origin, igneous pebbles being nearly absent. Along the Huatanay tributaries the sandstone is still dominant, but limestone makes up about 10 per cent and diabase 3 per cent to 5 per cent. Boulders of limestone exceeding 5 feet in diameter are found in this area. The relative scarcity of large boulders of sandstone appears to be due to the fact that closely spaced intersecting joint-planes break up this rock into cubes of a few inches on a side. That brown sandstone should rank first as the source of material is due (1) to the more precipitous slopes on the west border of the fan; (2) to the more abundant fragmental waste resulting from the weathering of sandstone as compared with limestone; (3) to the fact that those portions of the fan where limestone and diabase boulders were formerly most abundant (e. g., along the Huatanay river) have been most completely removed by stream erosion. It was noticed that limestone fragments are more abundant in the topmost beds of the fan—a natural consequence of the fact that the limestone occupied southern slopes and was more or less protected by a cover of snow and ice during the early part of the period of excessive aggradation. So far as observed, coarse, sandstone gravel forms the layer immediately in contact with bed rock.

Three types of material are represented in the fan: gravel, coarse to very coarse; sand, fine, compact; and adobe. The structure and composition of the gravel and sand have been discussed. Brown adobe occupies about an acre on the west bank of the Ayahuaycco Quebrada, where it attains a thickness of thirty feet and includes three bands of white lime silt. The material lies in horizontal beds, is impalpably fine but firm and compact. The adobe and associated beds are alike highly calcareous and are traversed by vertical root tubes encrusted with lime. This deposit, as well as the less extensive accumulations near Santa Ana church and at the mouth of the Ayahuaycco, differ in no essential from the beds of adobe and unconsolidated limestone abundantly displayed in the Cuzco Valley beyond the border of the fan. They are believed to represent the shores of ephemeral lakes which existed contemporaneously with the gravel-bearing streams.

Age of Deposits.

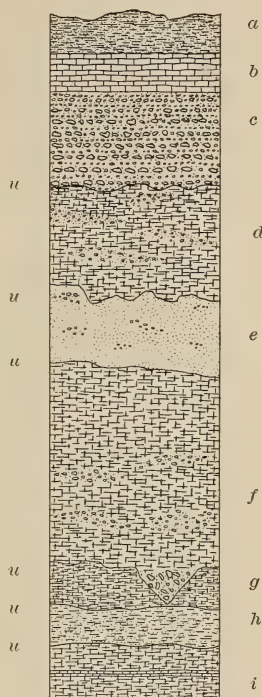
As previously stated, the Cuzco gravels are believed to have reached their greatest extent and thickness in late Pleistocene times. More recent deposits have, however, been superposed.

FIG. 8.



- a*, 40 ft., gravel, massive.
b, 4 ft., fine sand.
c, 7 ft., gravel, massive.
d, 6 feet, compact clay adobe.
e, 20 ft., coarse gravel, massive.
u, unconformity.

FIG. 9.



- a*, 2 ft., soil and adobe.
b, 2 ft., fine shell limestone.
c, 5 ft., gravel, coarse and fine, horizontal.
d, 6 ft., massive adobe, with lenses of gravel.
e, 4 ft., fine sand with gravel patches.
f, 10 ft., adobe with thin lenses of gravel.
g, 2 ft., compact adobe.
h, 2 ft., fine sand and clay.
i, 3 ft., adobe with thin band of shell limestone.
u, unconformity.

FIG. 8.—Sec. VII, Bank of unnamed tributary to Rio Sappi opposite the Rodadero.

FIG. 9.—Section VIII, Bank of the Chunchullumayo, near junction with Rio Huatanay.

Surface wash from the bordering slopes, controlled in amount and character by climatic changes, has probably been accumulating continuously since glacial times, and has greatly increased since human occupation began. Soil wash resting unconformably on the surface of the fan may be observed at favorable localities. On the lower sandstone slopes bordering the Cuzco

fan, where the fields may have been cultivated for five or six centuries, soil wash and associated deposits have accumulated to depths of ten to twenty feet at the base of the slopes. A section exposed on the bank of the Ayahuaycco Quebrada presents the following order of stratification :

<i>Recent deposits northwest bank of Ayahuaycco Quebrada.</i>		Feet
1.	Wash from hill slope and cultivated field, red-brown in tone, composed of sand and clay with inclosed rock pebbles and earth clods	1 1/4
2.	Ash, cross-bedded in layers 1/4 to 1 inch, composed of alternating bands of black charcoal, burnt grass, etc., and grey wood ashes. Fragments of bones, teeth, also of ancient pottery, are abundant. Near the base pebbles of sandstone and thin bands of sand are found	10
3.	Gravel, rudely stratified, composed of pebbles one to four inches in diameter; also scattered bones and sherds	8
4.	Sandstone ledge, on top of which lie two large limestone boulders not of local origin	4

The thickness of cover over deposits of ashes varies from one to eight feet within a distance of 300 feet along the Ayahuaycco Quebrada. The thickness and position of deposits of human origin is likewise variable. The recent date of the wood ash and overlying strata is plainly shown by the presence of sherds and of bones of modern types and by a comparison of the ash shown in section along the quebrada with that exposed in a bank 300 feet further east. In structure and composition the two are essentially alike, although one is the present city dump and the other is definitely interbedded with gravels and soil wash. An even more striking illustration of aggradation is the presence along the lower Ayahuaycco of a wall of Incaic or pre-Incaic design which had been buried by four to eight feet of gravel, partly stream-laid, partly washed from the slopes. This buried wall was exposed (about 1870) in cutting an artificial channel for the wet-weather stream which drains the quebrada. The original wall, resting on what is believed to be an eroded portion of the fan, is composed of hewn limestone blocks of excellent workmanship and has been continued upward by a poorly constructed retaining wall of stone and adobe which serves as a border for the fields below.* Similar buried walls were noted at other localities,

* For further details regarding this wall see Bowman: "A Buried Wall at Cuzco and its Relation to the Question of a pre-Inca Race," this Journal, vol. xxxiv, pp. 497-509, 1912. Bowman concludes that the burial of this wall may date from 2000 B. C. to 4000 B. C. Although such antiquity is possible, yet the geological conditions are satisfied on the basis of a much shorter period of time.

and at a point south of San Sebastian such a wall buried beneath the soil of a cultivated field is exposed in the valley of the Huatanay, where it stands plastered against the bank of

FIG. 10.



FIG. 10. Buried wall exposed in the bank of the Rio Huatanay.

the stream, twenty feet above the bed, like an ornamental border on wall paper (fig. 10). This wall, probably built to protect the fields from the summer overflow of the Huatanay,

has remained in place, while the canalized stream has entrenched itself in the sands and gravel bordering the Cuzco basin.

Ground Water.—A large proportion of the water which falls on the surface of the Cuzco fan is rapidly absorbed, and percolating downward through the porous gravels to a depth of 100 to 400 feet, emerges as springs along water courses and on the periphery of the fan. Springs are numerous in the lower part of Cuzco, and many open wells within the city reveal permanent supplies at a depth of fifteen to twenty-five feet. On the northeast border of the fan the direction of ground-water flow is southwest, following the rock slope beneath a thin superficial cover; on the west border, where similar relations exist, the flow is east. The high content of lime in well and spring waters is due to the presence of tiny fragments of limestone widely disseminated through the gravels in quantities sufficient to furnish calcareous cement for the partial consolidation of portions of the mass. One result of ground-water action, which has also an archæological bearing, is the presence of numerous small caves and pockets and shelves in the steeply inclined gravel walls,—cavities which mark the position of ephemeral seeps and areas of less consolidated material. The floor of these caves is covered with stratified sands and they appear to have been used extensively as sepulchres.

Landslides and creeps resulting from the action of ground water may be observed at numerous places along the ravines which trench the Cuzco gravels, where the conditions for their formation are exceptionally favorable. The alluvium rests on steep rock surfaces, coarse gravels overlie lenses of fine sand and adobe, the water courses follow deep, narrow canyons, cut in unconsolidated deposits, the amount of ground water is relatively large, and markedly fluctuating in response to periodic showers. Following an ordinary storm accompanied by a heavy downpour, the writer observed six small slides and numerous seeps along the Chunchullomayo in positions where vertical, dry gravel walls had been noted on previous days. In the heavier gravel masses trenched by gravel-walled canyons the effect of slides is chiefly to give the valleys an unsymmetrical shape with the steeper wall on the side toward which ground water flows. In valleys where one bank is gravel and the other gravel underlaid by rock, the lack of symmetry is very pronounced,—a perpendicular wall of gravel facing a moderate slope of gravel, decomposed rock and miscellaneous slide debris. Slides, mostly of small or of moderate dimensions, are conspicuous along the Sappi and the Ayahuaycco where they extend to the stream bed or remain as plasters attached to the walls. The southwest bank of the canyon portion of the latter stream is almost continuously faced with

slides like an artificial revetment. The northeast wall is marked by two slides, one immediately above and one immediately below the locality from which bones were excavated by the expedition of 1911. Moreover this wall is capped by a sloping terrace with an escarpment at its inner face, indicating that a mass of gravel $30 \times 300 \times 150$ feet has slid downward ten feet toward the valley axis. An examination of old slides as well as of those which have occurred within the last few years shows that except where decomposed rock forms the slipping plane there is no clean break between the gravel in place and the transported portion or between different portions of the slide material itself. Where sand or adobe lenses have been involved it is easy to determine both the fact and the amount of displacement, but in the massive gravel where evidence of stratification is absent, it is impossible to determine with assurance which is slide and which is original bank, especially after the low top escarpment has been obliterated by further sliding and soil creep. Two artificial trenches were cut into gravels across a plane, which on independent evidence is known to mark the contact of slide gravel with the original valley wall. In these cases neither the orientation of pebbles, nor a ragged contact, nor open spaces, nor effects of ground water gave evidences of displacement. A tunnel eleven feet long and with a cross section $4\frac{1}{2} \times 3$ feet was sunk into the steep gravel wall of the Ayahuaycco Quebrada at the exact point from which human bones were taken by the members of the Peruvian Expedition of 1911. The section exposed is entirely gravel, consisting of pebbles of brown sandstone (90 per cent), gray sandstone (9 per cent), limestone and igneous fragments (1 per cent), ranging in size from one-half inch to four, rarely six inches, and so firmly packed that no timbering of the tunnel was required. The material is uniform in texture, contains no bands or lenses of sand, no division planes, or other unmistakable evidences of stratification. Even the pebbles are variously oriented and about a third of them, including many thin, flat slabs, slope at angles between 60° and 90° to a horizontal surface. The relation of landslides to the gravels in which human bones were found by the Expedition of 1911 is discussed by Doctor Eaton (see p. 5) and need not be further considered here. In certain of the slides the gravel pebbles appear to have moved differentially among themselves, to have assumed an angle of repose by internal readjustment, somewhat analogous to the movement of particles involved in glacier motion. It would therefore appear impracticable to determine the position and dimensions of landslides and slumps in the unsorted portions of the Cuzco gravels. Evidence of displacement indicates the presence of landslides, but unfortunately the absence of such evidence does not prove the absence of landslides or "creep" at any given point.

The lower Ayahuaycco Quebrada furnishes evidence of the manner in which slides modify valley form and aid in the burial of extraneous matter. The stream has occupied this portion of its valley since about 1870, when an artificial readjustment of drainage was effected. During these forty years the stream has cut a ravine twenty to thirty feet deep and about twenty feet wide. Three slides are visible within one hundred feet. The one nearest the stream's mouth covers about twenty square feet and is pasted against the vertical wall as a patch two feet thick. In this case stratification is well marked, but the break is so completely healed that, without the discordance in bedding, the displacement could not be detected. The second slide blocked the stream, which, rising to the crest of the dam, cut downward and formed a new floor. Later trenching developed a terrace 12×20 feet, the edges of which reveal material identical with the gravel in the original bank. The material of the slide, the material deposited by the stream, the material fallen on the terrace, and the material of the standing wall are indistinguishable in structure, texture and composition. The fact of the slide is demonstrated by a broken lense of sand revealed by an artificial trench. From the gravels of the slide midway between top and bottom were excavated two pieces of imported pottery, relics carried by the stream or fallen from the top of the bank. A deeper cutting of the channel, accompanied by smoothing of the slope, would have left those fragments of household furniture firmly embedded in a wall of gravel beneath twenty feet of sediment, all so like the gravel of the original fan as not to be differentiated with certainty. It seems reasonable to suppose that much greater thicknesses of sediment forming much higher banks of gravel may have passed through similar stages.

Erosional History.—The present position and structure of the Cuzco gravels and the general physiographic relations of the area suggest the outline of the original deposits as indicated on the map (fig. 2). The dissection of the fan probably began with the establishment of permanent drainage in the Sappi, whose relatively large watershed and its fall of about 400 feet per mile gave it considerable erosive power over the gravels marking its path. Coincident with the cutting of the Sappi canyon, but at a slower pace, its tributaries were cut and the front of the fan was developed into cliffs by headward erosion of short, steep, wet-weather streams assisted by ground-water activities. The Ayahuaycco probably originated as a line of drainage at the western edge of the fan and worked progressively north and east, following the rock slope downward and maintaining, approximately, the present relation of one bank on or near rock and the other bank cut in gravel.

That the dissection of the Pleistocene and recent gravels has

not been progressively continuous, is shown by the terraces along the upper Huatanay (Sappi) and still more plainly by the well-developed terraces, two to five in number, flanking the streams entering the Cuzco valley beyond the limits of the fan. No well-marked terraces persist in the upper Ayahuaycco Quebrada, a location unfavorable for their preservation. The canyon is narrow, the banks are of gravel or of gravel on rock, and the stream is fed by wet-weather torrential tributaries with gradients of over 1500 feet per mile. Here, as along other streams entering the Cuzco valley, terraces may have been buried and re-excavated many times in response to minor climatic fluctuations during historic as well as prehistoric times, the evidence for which is conclusive. It is unprofitable, from a geological standpoint, to work out the details of erosional history in and about Cuzco, because of the extensive modification of slopes and terraces resulting from cultivation and flood-water irrigation. However, the evidence indicating periodic destruction and building of terraces, even within the past one hundred years, removes the necessity of ascribing great antiquity to animal bones, parts of human skeletons, and fragments of pottery found along stream banks and which may have been deposited on terraces or on banks, or in the numerous small cave-like openings in the gravels, to be transported, buried, or re-exposed during alternating processes of deposition and degradation. It is interesting to note that in the canyoned tributaries of the Sappi and of streams leading from the limestone plateau and from the sandstone highlands bordering the Cuzco basin on the south,—valleys from which terraces and slides have been removed and whose banks offered no temptation to occupation, valleys whose present precipitous gravel walls are clearly of glacial age,—no traces of human occupation were revealed by careful search. From these same gravels, however, mastodon bones have been collected, on the Huancaro and in the lower Cuzco valley. The fact that these bones from the Ayahuaycco gravels are of modern types (see article by Eaton, p. 5) obviously corroborates this view of depositional history, and also indicates important climatic changes since the Spanish conquest.

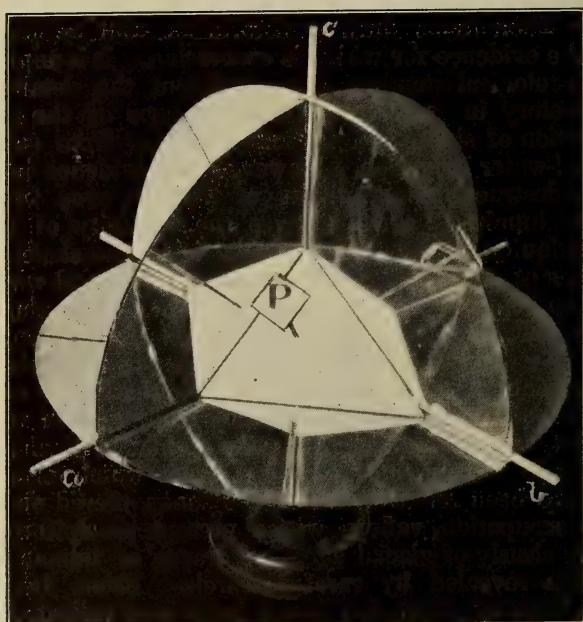
It will be noted that the explanations given in this paper are chiefly of negative value so far as archæological research is concerned. That man existed in South America in glacial or preglacial times, and that the human bones discovered in the Ayahuaycco Quebrada "appear to be from 20,000 to 40,000 years old" as tentatively held by Bowman,* is not definitely disproven by the field studies of the present writer. On the other hand, the geologic data do not require more than a few hundreds of years as the age of the human remains found in the Cuzco gravels.

* This Journal, vol. xxxiii, p. 321, 1912.

ART. IV.—*A Simple Model for Illustrating the Symmetry of Crystals*; by ALEXANDER H. PHILLIPS.

For several years past I have been using in my class work a model, of very simple construction, to illustrate the symmetry of the various types of crystals. It has been very helpful and

FIG. 1.



most effective in simplifying some of the points in crystallography, which have always seemed most difficult for the ordinary student to grasp without a demonstration.

The model as shown in the figure is constructed of a horizontal disk of tin, representing the plane of the lateral axes or the equator, in the equatorial types. At right angles to this disk and at right angles to each other are two semicircular disks; these three planes divide space in the northern hemisphere into the usual four quadrants, as in those systems in which the axes are at right angles and represent the axial or diametral planes, the intersections of which will represent the axes $a : b : c$. At the center of the model a socket is cut in the

stand and holes in the disks, large enough to allow easy motion to a lead ball, of an inch and a half in diameter, which forms a universal joint; into this lead sphere a knitting needle of proper size is set in the direction of the radius and upon the end a small card, *P*, is placed which represents the position and inclination of the crystal face under consideration. The lead ball being so much heavier than the needle, the pole may be placed in any position whatever within the quadrant and remain stationary.

At *b*, the vertical disk is not soldered to the equatorial disk, but a slot is cut wide enough to allow the pole to pass to the right back quadrant. The pole thus, in the prism zone, has a range of 180 degrees and any face in this zone may be represented by the pole. There is a similar slot at *c*, which allows the pole to pass from the right to the left front quadrants, allowing a range of 180 degrees in each dome zone. The only quadrant not accessible to the pole is the back left. The right front quadrant is lined with mirrors, which represent planes of symmetry; by placing the pole in the required position any crystal face is represented, and if wished, a card may be cut and placed in the mirrors, when the exact shape of the form will be reflected. The model in the figure represents the holohedral orthorhombic class; with the pole in any position within the quadrant, not in contact with a mirror, will represent a pyramid, as the eight reflected poles may be counted, representing the eight possible faces of the form. When the pole is moved in contact with one of the mirrors (the lead ball should be placed a little eccentric in favor of the octant in which the mirrors are placed to permit of this), it will be seen that two poles will be in contact, indicating that two faces of the most general form, the pyramid, will coincide, yielding a form of four faces, a dome or prism, according to the position of the pole.

When the pole is placed in any one of the three angles of the octant, it will be seen that four of the eight poles of the pyramid coincide forming the pinacoids of two faces, which are also shown as fixed in forms, as there is but one position for the pole in the angle.

For the tetragonal system an intermediate mirror may be placed at 45 degrees to the one containing the crystallographical axes; the ditetragonal pyramid will be reflected by the mirrors, when a card is placed between them, as in the figure, and 16 poles may be counted. For the hexagonal system the intermediate mirror is placed at 30 degrees, when 24 reflections may be counted. For the isometric system three pieces of tin are cut and soldered at their intersection, the trigonal axis of the system, so as to divide the octant symmetri-

cally into eight similar triangles, representing the six diagonal planes of symmetry of the system, three of which are represented in an octant. If when this set of three planes is placed in the octant, one of the six triangular spaces is lined with mirrors and the pole placed within it, 48 reflections may be counted or the hexoctahedron is illustrated. The remaining six forms may be represented by placing the pole in the six possible positions, the three sides and the three angles of the triangle.

If desired, the disks may be graduated and marked off in degrees, when any particular dome or prism may be illustrated.

The model is also most convenient for illustrating the method of the two-circle goniometer, as the equatorial disk represents the vertical circle of the instrument and the vertical disk of the model the meridian of reference. The relation of the two angles measured on the instrument, to the pole of the face, is simply shown in the model, as one corresponds to the longitude and the other to the complement of the latitude.

In the gnomonic projection the plane of projection would be tangent to the two vertical disks of the model at c , and the intersections of these two disks with this plane would be the lines along which the two angular coördinates x and y of any face is measured; the face being represented by the point of intersection of the pole with this tangent plane. The trigonometrical relations of the coördinates x and y , the point representing the face and the two angles measured on the goniometer, cannot be more simply demonstrated than by this model.

Princeton University, May 3, 1913.

ART. V.—*The Chemical Composition of the Alkaline Rocks and its Significance as to their Origin*; by C. H. SMYTH, JR.

As the alkaline rocks constitute one of two closely related groups which, taken together, comprise all igneous rocks, it is evident that any complete discussion of the question of their origin must involve a consideration of the origin of igneous rocks in general, leading, thus, to the largest problems of structural and dynamic geology, even including, in the last analysis, the origin and internal constitution of the earth. This being the case, it is safe to conclude that a final solution of the problem will be attained only by a long series of approximations. Recognizing this fact, and making no attempt at exhaustive treatment, the present discussion deals only with certain phases of the problem, accentuating relations whose significance appears to be greater than has been recognized in earlier contributions.

The title of this paper, and of others dealing with the same problem, would seem to imply that, in spite of their broad relations, the alkaline rocks have something distinctive in their character which justifies their more or less independent consideration; and it need hardly be said that this appears in the facts that they are marked by comparative rarity and by certain peculiarities of chemical and mineralogical composition.

The comparative rarity of the alkaline rocks, as contrasted with the subalkaline rocks, has been generally, though often tacitly, recognized by petrologists. Subalkaline rocks are taken as a matter of course, as the normal and expected thing, but every newly discovered occurrence of alkaline rocks is made the object of special study, as something out of the ordinary and of unusual interest.

A more precise statement of this quantitative relation has recently been made by Daly,* who, after careful study of the question, concludes that the alkaline rocks make up less than one per cent of all igneous rocks.

This is a fact of much importance in its bearing upon the origin of the alkaline rocks, and, as shown by Daly, points distinctly to the conclusion, supported by many other lines of evidence, that they are derivative in their nature, products of a special variation of the normal subalkaline magma. In other words, the earth's crust is composed essentially of rocks which are products of the normal differentiation of subalkaline magmas, and which constitute 99 per cent of the 95 per cent

* R. A. Daly: *The Origin of Alkaline Rocks*, Bull. Geol. Soc. Am., xxi, pp. 87-118, 1910.

of igneous rocks of which Clarke* estimates the lithosphere to consist. The remaining igneous rocks, amounting to only one per cent, are derived from the same magmas, but are products of some exceptional conditions of differentiation, which find their expression in the peculiar chemical and mineralogical composition of the resultant alkaline rocks.

These relations may, perhaps, be made clearer, so far as the major constituents of rocks are concerned, by a comparison of the composition of igneous rocks in general with that of alkaline rocks. The mean composition of igneous rocks has been estimated by averaging the results of large numbers of analyses, and, on the basis of somewhat different data, Clarke, Harker and Washington have arrived at the results given below, in I, II and III, the figures in each case being recalculated, by Clarke, to one hundred per cent, on a water free basis.

	I	II	III	IV	V
SiO ₂	61.82	60.76	58.96	59.19	62.46
TiO ₂.....	.75	.53	1.05	.81	.56
Al ₂ O ₃	15.51	15.87	15.99	16.51	18.07
Fe ₂ O ₃	2.67	4.92	3.37	3.02	2.24
FeO.....	3.45	2.78	3.93	4.17	2.31
MnO.....	.....	.....	.....	.13	.08
MgO.....	4.02	3.82	3.87	3.93	.97
CaO.....	4.96	4.97	5.28	6.47	2.57
Na ₂ O.....	3.51	3.28	3.96	3.39	5.58
K ₂ O.....	3.04	2.85	3.20	2.12	5.02
P ₂ O ₅.....	.27	.22	.37	.26	.14
	100.00	100.00	100.00	100.00	100.00

- I Average Igneous Rock, Clarke, F. W., Data of Geochemistry, Bull. 491, U. S. Geol. Survey, p. 25, 1911.
- II Average Igneous Rock, Harker, A., Tertiary Igneous Rocks of the Isle of Skye, Mem. Geol. Survey United Kingdom, p. 416, 1904.
- III Average Igneous Rock, Washington, H. S., Chemical Analyses of Igneous Rocks, Prof. Paper, U. S. Geol. Survey, No. 14, p. 106, 1903.
- IV Average Composition of 89 Diorites, Daly, R. A., Average Chemical Composition of Igneous Rock Types, Proc. Am. Acad. Arts and Sci., xiv, p. 238, 1910.
- V Average Composition of 23 Alkaline Syenites, Daly, R. A., Op. cit., p. 220.

The agreement of these estimates is sufficiently close to warrant the conclusion that they must afford a fair approximation

* Clarke, F. W.: The Data of Geochemistry, Bull. 491, U. S. Geol. Survey, p. 31, 1911.

to the truth, while the nature of the data used by Clarke is such as to inspire particular confidence in his results.

The figures of I, then, may be taken as representing the mean composition of the igneous rocks, or the average magma, including not only the abundant subalkaline rocks, but the less common alkaline rocks. Indeed, since the latter, as stated above, always receive special attention, it is probable that a disproportionately large number of their analyses are used in making up the average, thus tending to bring the results slightly closer than they should be to the average for alkaline rocks. But whether or not this is so, it is evident that the mean composition, as given, is distinctly subalkaline in character, as is clearly shown by comparison with Daly's average of the composition of eighty-nine diorites, given in IV, and representing a typical subalkaline magma, slightly less siliceous than the average rock, and with corresponding differences in other respects, but, on the whole, showing fairly close agreement with I.

On the other hand, the same writer's average of twenty-three alkaline syenites, given in V, while having nearly the same silica content as the average rock, differs from it markedly in other respects, particularly in having higher alumina, lower magnesia and lime and much higher alkalies, features generally characteristic of alkaline rocks. In view of the fact, stated above, that the alkaline rocks are included in the general mean, it is clear that, if the figures of V are at all typical, the alkaline rocks must exist in comparatively small quantity, while it is equally clear that the average magma must be distinctly subalkaline. The latter magma is, obviously, of world-wide extent, while the former occurs in relatively limited amount, but at widely scattered points. Differing from the average rock only in the relative percentages of elements common to both, the alkaline rocks are to be regarded as derivatives of the subalkaline magma rather than as something essentially distinct.

In view of the small amounts of alkaline rocks, it is evident that the moderate concentration in them of such abundant constituents as alumina and the alkalies would not materially affect the composition of the greatly preponderant average magma, while less abundant constituents may exist in the latter in such small quantities as to escape detection, and yet be markedly concentrated in the derivative alkaline fraction.

Quite different from this conception of the derivation of alkaline from subalkaline magmas is the view of Becke,* who suggests that the constituents of the two types of magma were

* Becke, F. : *Die Eruptivgebiete des böhm. Mittelgebirges und der amerik. Andes*, Tschermak's Min. und Petr. Mitt., xxii, p. 247, 1903.

separated by gravity, during a gaseous stage of the earth, into an upper, subalkaline, and a lower, alkaline, layer which furnish the respective types of rock, as well as intermediate varieties due to mixing.

Jensen* advances the hypothesis "that alkaline rocks are derived from . . . Archæan saline beds which, by chemical attacks on the adjacent sediments, have given rise to an alkaline magma in the process of metamorphosis. This magma has been squeezed laterally into continental areas and has undergone differentiation, or it has mixed with other magmas, chiefly basic, and then differentiated."

Daly,† as previously stated, regards alkaline magmas as derived from subalkaline magmas, but finds the cause of differentiation in the assimilation of limestone, both the carbon dioxide of the latter, and the lime, being active agents. These agents he views as disturbing the chemical equilibrium of the magma, thus tending to differentiation and the resultant production of the alkaline rocks.

Harker‡ differs from Daly in seeking the chief cause of the special differentiation that produces alkaline rocks in mechanical, rather than chemical, conditions and, noting an association of this "branch" of rocks with the Atlantic type of structure, as defined by Suess, concludes that both are products of the same mechanical conditions.

Thus, the hypotheses mentioned explain alkaline magmas as primordial or as due to melting of saline sediments, with some assimilation, to assimilation and consequent differentiation, or to differentiation caused by crustal disturbances.

As already stated, the present writer considers the alkaline magmas to be derived from the subalkaline magmas, as indicated not only by the relatively small amount and local occurrence of the former, but also by the association of the two types, the existence of intermediate varieties and the successive appearance of both in a given region. This view is further supported by certain peculiarities of chemical composition of the alkaline rocks which, taken in conjunction with their small quantity, are thought to be very suggestive as to the agents and conditions of their origin.

As their name implies, and as shown by the analyses given above, the alkaline rocks are, as a rule, high in alkalis, particularly sodium, but, for the present purpose, attention is directed, not to the dominant constituents, but rather to those

* Jensen, H. I.: *The Distribution, Origin and Relationships of Alkaline Rocks*, Proc. Linn. Soc. N. S. Wales, xxxiii, pp. 585-586, 1908.

† Daly, R. A.: *Origin of the Alkaline Rocks*, Bull. Geol. Soc. Am., xxi, pp. 87-118, 1910.

‡ Harker, A.: *The Natural History of Igneous Rocks*, pp. 102 and 330 et seq., 1909.

which, though small in amount, are thought to possess a peculiar significance.

The data in regard to these minor chemical constituents of rocks have been summarized by Washington* in an exceedingly interesting and suggestive paper. With reference to the rarer elements, he concludes that, in the alkaline rocks, there is a greater relative abundance of lithium, beryllium, cerium, yttrium, and other rare earth minerals, zirconium, uranium, thorium, sulphur as SO_2 , fluorine, chlorine, barium and perhaps tin. In the subalkaline rocks, on the other hand, there is a concentration of titanium, vanadium, manganese, nickel and cobalt, chromium, platinum metals and, possibly, phosphorus.

A tabulation of Washington's somewhat more detailed statement, giving the elements concentrated in sodic, potassic, ferriferous, magnesian and calcic magmas, respectively, is as follows :

Alkaline		Subalkaline		
Sodium Magmas	Potassium Magmas	Iron Magmas	Magnesium Magmas	Calcium Magmas
Li Be Ce Yt Zr Ur Th S (as SO_2) F Cl Sn ?	Ba	Ti Va Mn Ni Co	Cr Pt	Cr ? P ?

The contrast between the two main sections of the table is striking. The elements of the second section, those concentrated in subalkaline magmas, are such as occur in ultrabasic segregations, nearly always in basic igneous rocks. On the other hand, the elements of the first section, those concentrated in alkaline magmas, fall into two groups:—elements characteristic of, and largely confined to, pegmatites, and “mineralizers.”

The frequent association of these two latter classes of elements in pegmatites is generally recognized as having a direct genetic

* Washington, H. S. : The Distribution of the Elements in the Igneous Rocks, Trans. Am. Inst. M. E., xxxix, pp. 735-764, 1909.

cause, the mineralizers being the active agents, which, through their affinity for the rarer elements, with which they form mobile compounds, concentrate the latter in the magmatic extracts which furnish the materials for pegmatitic intrusions.

As a result of this process, the rarer elements of a normal magma, which may originally have been so diffused through the mass as to be hardly perceptible, become concentrated in a comparatively small amount of magma, which, being tapped off separately, solidifies as a rock different in composition from that representing the original magma, and characterized by the presence, in relatively large amounts, of the rare elements and mineralizers, although, as a rule, the latter are in large part dissipated.

Indeed, but for this process, many of the rare elements would doubtless be unknown to us. Even with such a method of concentration in existence, radium, in spite of its striking properties, was discovered only through the exercise of extraordinary skill and patience; and there can be little doubt that there are other elements with such limited tendency toward natural concentration as to put their detection beyond our present means of accomplishment.

Thus, there is a very general tendency in magmas toward the segregation of the rare elements and the mineralizers in a distinct part, usually erupted separately and always in much smaller quantity than the average magmas. The composition of the latter, moreover, is not perceptibly changed by the withdrawal of the rarer elements, since, compared with the total mass, their quantity is entirely negligible. This, however, is not necessarily true of the gaseous constituents, as they may have been present in considerable amount, and subsequently dissipated.

Between these phenomena and those presented by the alkaline and subalkaline rocks as a whole, the analogy is too striking to be accidental, in spite of the great difference in order of magnitude. This difference of scale is such that no close association, either in time or in space, can be expected in the case of the two groups of rocks, like that existing between pegmatites and their associated rocks, but contemporaneous or successional association of the two branches, though less intimate, is practically universal; while the quantitative relation between the alkaline and subalkaline rocks on the one hand, and the pegmatites and their associated rocks, on the other, are analogous, just as are the chemical relations. With reference to the latter, it is true that definite analytical data, as to the quantities of the rarer elements mentioned above, are meager, but, so far as they exist, they justify the conclusion reached; and substantiation is afforded by field relations, the rare ele-

ments occurring in pegmatites associated with alkaline rocks in whose parent magmas the elements in question must have occurred in a state of relative concentration as compared with their amounts in subalkaline magmas.

Referring to cerium, yttrium, and other rare earth metals, together with thorium and uranium, Washington* says: "Minerals containing them are commonly associated with acid pegmatites, which, judging from occurrences in Norway, Greenland and elsewhere, are most apt to be sodic, though the few determinations available of the rare earths are in highly potassic igneous rocks." Thus, while here, as elsewhere in the paper, Washington distinguishes between sodic and potassic magmas, he refers the elements in question to one of the two, or in other words, to alkaline magmas.

He states that lithium favors the sodic rather than the potassic magma, while beryllium has similar associations. "Few analyses exist of such beryl-bearing rocks and beryllia has seldom been estimated separately from alumina in rock-analysis, but such data as are available and the common mineralogical association of beryllium and sodium point to the conclusion that the element is most at home in sodic magmas."

Zirconium, he says, "may be considered to be a characteristic minor chemical constituent of the sodic rocks, whether the silica be so high that quartz is present, or whether it be so low that nephelite is abundant, as in the nephelite-syenites and phonolite."

In the case of fluorine "there seems to be a marked tendency on its part to favor especially rocks which are high in soda. This is seen in the fact that fluorite is frequently present as an original constituent of such highly sodic rocks as nephelite-syenite, phonolite and tinguaitite; the association of fluorine and sodium in certain rare minerals, as leucophanite, meliphanite, johnstrupite, rinkite, etc., which are almost always found in sodic rocks; and by the recent discovery by Lacroix of sodium fluoride in nephelite-syenite of West Africa."

"Chlorine resembles fluorine in being a pneumatolytic constituent, and is present in igneous rocks, chiefly in the minerals sodalite and noselite, which are almost wholly confined to sodic rocks and especially those which are low in silica, in this resembling the occurrence of SO_2 ."

These extracts from Washington's paper serve to make clear the general abundance of rare earths and related elements, and of the mineralizers, in the alkaline rocks, as compared with the subalkaline rocks. These elements may be perceptibly abundant throughout large masses of alkaline rocks, or they may appear only in the associated pegmatites as a result of concen-

* Loc. cit.

tration from the main magma by a process in which the mineralizers are universally recognized as having played a leading part.

Not only are the rare elements thus concentrated in the pegmatites, but the alkalis themselves appear in muscovite, lepidolite, microcline, albite, etc. In other words, the elements whose relative abundance is a characteristic feature of the alkaline rocks in general, are concentrated in pegmatites through the agency of mineralizers in virtue of the power of the latter to unite with these elements and yield mobile compounds which, from their distinctive physical character, are capable of being segregated from the average alkaline magma. Now, since the alkaline rocks, as a whole, differ from the subalkaline rocks in containing larger proportions of these same elements, is it not a reasonable conclusion that the same agents have effected the concentration in both cases? In other words, the facts stated above suggest that the alkaline rocks represent magmas of exceptional composition derived from ordinary subalkaline magmas through the agency of mineralizers, and, thus, the relation between the two branches of rock is, to some extent, analogous to that existing between a local magma and its pegmatitic phases.

According to this view, the pegmatites of an alkaline region represent a final stage in the process of concentration of certain elements, which started in a subalkaline magma, and was effected through the agency of mineralizers. The power of these agents is due to their own mobility, which enables them to permeate a magma, together with their capacity to form mobile compounds with certain elements. As a result of these two properties, the mineralizers are able, under favorable conditions, to extract these elements from the magma and to transfer them elsewhere. The elements peculiarly subject to such extraction are clearly shown by the pegmatites, and the same elements are extracted to form alkaline rocks.

So far as the abundant elements of the alkaline rocks are concerned, there is no difficulty in accepting their concentration as the result of diffusion, fractional crystallization, gravity or whatever agents may effect the usual differentiations of magmas. But such an explanation of the concentration of the rare elements in alkaline magmas seems wholly inadequate and we are forced to have recourse to some agent capable of extracting minute quantities of rare elements from the subalkaline magmas and concentrating them in the alkaline magmas. The high atomic weights of many of these rare elements and their extreme degree of dilution would both, presumably, tend to prevent differentiation by diffusion, and the only agents apparently capable of performing the task are the mineralizers.

The simultaneous concentration of the rare elements and the alkalies can hardly be fortuitous, and if the mineralizers accomplished the former there can be little doubt that they did the latter as well, but to a smaller degree.

While the essential features of the production of pegmatites are generally accepted as established, many details remain to be worked out, particularly on the mechanical side. If this is true of, relatively, so small an operation, it is not surprising that one of the magnitude here under consideration should be wrapt in obscurity. Even if the probability of the hypothesis advanced be admitted, it constitutes only one step in a long series of most complex problems.

One of these problems may be referred to on account of the importance that has been ascribed to it from the genetic standpoint. First emphasized by Iddings* in his classic paper on the origin of igneous rocks, the distribution of the alkaline and subalkaline rocks has since been made the basis of the broad generalization that, so far as may be judged by the conditions of Tertiary and recent time, alkaline rocks occur in regions of radial dislocation, the "Atlantic" regions of Suess, while subalkaline rocks occur in regions of tangential dislocation, "Pacific" regions of Suess.

This generalization, first made by Harker† and later, independently, by Becker‡ and by Prior,§ has, as already indicated, been taken by the former as the basis of a mechanical hypothesis to account for the distribution of alkaline and subalkaline rocks. Without trying to determine details, he concludes that distinct types of differentiation are effected by the two types of crustal disturbance, the one, radial, giving alkaline rocks, the other, tangential, giving subalkaline rocks. The differentiation takes place chiefly in a horizontal direction and, as a result, very extensive regions are underlaid, during a single igneous epoch, by alkaline, or subalkaline, magmas, as the case may be, which determine the type of igneous rocks for the region and epoch. As a result of changing type of crustal disturbance, a given region may be underlaid by alkaline magmas at one time and by subalkaline magmas at another, with corresponding changes in its igneous rocks.

The writer's conception is quite different, since it regards the subalkaline magmas as of world-wide extent, and the alkaline magmas as derived from these, when local conditions are

* Iddings, J. P.: *The Origin of Igneous Rocks*, Bull. Phil. Soc. Washington, xii, pp. 89-202, 1892.

† Harker, A.: *The Natural History of Igneous Rocks: I. Their Geographical and Chronological Distribution*, Science Progress, vi, pp. 12-33, 1896.

‡ Loc. cit.

§ Prior, G. T.: *Contribution to the Petrology of British East Africa*, Mineralogical Magazine, xiii, pp. 228-263, 1903.

favorable, without any regional transfer of magma in a horizontal direction. If this conception is right, it may still be true that the final determining factor for the genesis of alkaline rocks is a mechanical one, and, perhaps, as suggested by many occurrences, the necessary local conditions for the derivation of alkaline from subalkaline magmas most often exist in regions of radial dislocation. As to the precise character of such mechanical control, it is, of course, impossible to speak with even an approach to certainty, for we are here brought face to face with the still unsolved fundamental problems of vulcanism. It may be that, in very unstable regions, with belts of intense lateral thrust in which vulcanism is greatly developed, subalkaline rocks are intruded and extruded without opportunity for the associated mineralizers to effect the differentiation necessary to produce alkaline magmas. Whatever the mechanical conditions needful to cause solid, but potentially molten, rocks to become liquid (a much discussed problem wholly transcending the limits of this paper), in regions of such instability, intrusion and eruption may follow so rapidly upon melting that no opportunity is afforded for the separation of alkaline fractions. Instead, over vast areas, we find a monotonous assemblage of basalts, andesites, etc., typical subalkaline rocks.

In the more stable regions, on the other hand, where, instead of typical mountain-making due to lateral thrust, radial displacement prevails, magma basins may remain, for long periods, undisturbed by external agencies, and, if the proper conditions of pressure, temperature and viscosity exist, the mineralizers have the opportunity to exert their selective influence and extract from the mass those constituents with which they readily form mobile compounds. In other words, alkaline magmas may be formed under relatively stable conditions which admit of a long continued delicate adjustment of equilibrium. Such conditions must necessarily be rare, a fact with which the comparative rarity of alkaline rocks is in harmony.

Iddings* holds that stable conditions may prevent differentiation, and this is doubtless true for some types of differentiation, but where it is a process of magmatic extraction, such as is here considered, stability of conditions may be more favorable.

The magmas formed under these conditions are tapped off by vertical fissures and give rise to intrusions and extrusions of alkaline rocks. Presumably, too, the vertical fissures sometimes play an important rôle in permitting the active circulation of mineralizers through relatively rigid and, thus, but for the mineralizers, stagnant, bodies of magma.

* J. P. Iddings: *Igneous Rocks*, i, p. 292, 1909.

In this connection, it is of interest to note that Suess* says: "Thus the question arises whether diminution of calcium and magnesium in the Atlantic hemisphere may not stand in some connection with the progress of consolidation."

These suggestions, whose exceedingly hypothetical nature can not be too strongly emphasized, obviously are based upon the view, adopted throughout the discussion, that, in every region of alkaline magmas, large reservoirs of subalkaline magmas exist from which the former were derived. Whether or not intrusion and extrusion of such subalkaline magmas would precede the formation of the alkaline magmas would depend upon local conditions. A period of active mountain-making, with attendant intrusion and extrusion of subalkaline rocks, might be followed by a period of relative stability with the delicate adjustment of conditions necessary for the elaboration of alkaline magmas. Or, on the other hand, it might equally well happen that the subalkaline magmas would remain at depth, while the alkaline magmas reached higher levels. In dealing with phenomena of such a large order of magnitude, involving not only great bodies of magma, but, also, long periods of time, determinable relationships can hardly be expected.

In brief, the association of alkaline and subalkaline rocks, with distinct types of crustal disturbance, in so far as it may exist, is ascribed to the presence or absence of opportunity for the mineralizers to exert their influence as agents of differentiation. The mineralizers are regarded as the fundamental factor in the process, the mechanical conditions as affording secondary control, which, though perhaps in part subject to Harker and Becke's generalization as to distribution, may ultimately prove wholly independent of it. Much more thorough investigation is required before the extent and nature of the relations between petrologic and tectonic types can be established, and, while some connection doubtless exists, there can be no question that the relation is less direct and vastly more complicated than is implied by the foregoing bald statement or than could be expressed by any statement at the present time.

If, as here maintained, the magmas contain, within themselves, the essential agents of differentiation, it must follow that when these agents are allowed, by surrounding conditions, to operate, their effect is cumulative and, thus, intensified with the passage of time. The separation of an alkaline fraction from a subalkaline magma implies a concentration, in the former, of the agents which caused the differentiation. It necessarily results that the derivative magma has a greater tendency to differentiate than the original subalkaline magma had.

* *Op. cit.*, iv, p. 590.

Thus, the alkaline magmas must tend more than the subalkaline magmas, to separate into fractions of diverse composition and, in view of the elements which concentrate in alkaline magmas, some of these fractions will naturally contain rare minerals. Moreover, the production of small fractions exceptionally high in alkalis necessarily implies the production of corresponding fractions of complementary composition, and therefore high in other constituents. How closely these conclusions are in harmony with well-known facts, it is hardly necessary to say, since the great range of chemical and mineralogical composition shown by alkaline rocks in limited areas, the frequent occurrence, in them, of rare minerals and the not uncommon presence of highly calcic rocks, are among the familiar facts of petrology.

Of interest in this connection is Vogt's* statement that, in so far as limited miscibility may play a part in magmatic differentiation, it would be most likely to occur in rocks rich in mineralizers.

Thus, we arrive at the conclusion that the pegmatite dikes of such a region as the alkaline province of Christiania are but the last step in a somewhat discontinuous but still causally connected series of operations, differing vastly in degree rather than in kind, starting in the normal subalkaline magma and effected primarily through the agency of mineralizers, subject to secondary mechanical control.

It is hardly necessary to say that this hypothesis has much in common with the views promulgated by the French petrologists† in so far as the potency of mineralizers in igneous activities, and especially in connection with magmatic differentiation, is concerned.

On the other hand, it differs materially from Becke's hypothesis of a primordial gaseous separation, in a vertical sense, of alkaline and subalkaline materials. From Harker's hypothesis, it differs essentially in ascribing the chief function to mineralizers rather than to mechanical conditions and in regarding alkaline magmas as local derivatives of the universal subalkaline magma, instead of assuming separation of the two types by a horizontal differentiation of regional magnitude. Jensen's hypothesis is based upon melting of early alkaline and saline sediments, with some assimilation and mixing, and is, thus, essentially different from the views here advanced. Daly's hypothesis has much in common with the writer's, though based upon assimilation, but the assimilation postulated is of limestone and it is to the carbon-dioxide of this rock that

* J. H. L. Vogt, *Die Silikatschmelzlösungen*, II, p. 229, 1904.

† Cf. A. Michel-Levy: *Note sur la classification des Magmas des Roches Éruptives*, Bull. Soc. Geol. France (3), xxv, pp. 326-377, 1897.

the chief function is ascribed, while in certain cases it is considered probable that magmatic carbon-dioxide may have been effective, in the absence of limestone.

It need hardly be said that the present hypothesis is not offered in controversion of any of those above mentioned, but merely as a suggestion arising from viewing the problem from another standpoint. As a matter of fact, the several hypotheses have certain features in common, despite great differences of emphasis, and it is entirely possible that all the various agencies appealed to may play a part in the complex operations under consideration.

While not explicitly stated, the writer has, throughout the discussion, implied the belief that the mineralizers are magmatic or "juvenile" rather than resurgent. It would, indeed, be difficult to reconcile any other view with the hypothesis as here presented. This is clearly indicated by the previous statement to the effect that the magmas are regarded as containing within themselves the agents of differentiation. Indeed, the hypothesis is merely a particular application of the broad principle that magmatic gases are a large and vital factor in the system of terrestrial circulation.

In this respect, the hypothesis is fundamentally different from that of Daly, since it implies potential alkaline magmas anywhere, without reference to the nature of associated sediments or even to the existence of any sediments whatever; while Daly regards the formation of alkaline rocks as dependent, in most cases, upon the presence of limestones which furnish the necessary carbon-dioxide.

Thus far, the question as to which mineralizers were most potent as agents of differentiation has not been considered, this being, not only a most obscure matter, but also of secondary importance. Viewing the mineralizers as magmatic, it is probable, on general grounds, that water, above the critical temperature, or even, at some stages, dissociated, was a large, if not the largest, factor. According to Arrhenius,* aqueous gas would tend to extract carbonic acid, hydrogen sulphide, combinations of univalent ions, such as those of chlorine, fluorine and boron, with the most positive ions, like the alkali metals, rare earths and, less often, the alkaline earth metals. In other words, water, under magmatic conditions, tends to extract the elements characteristic of the alkaline rocks, rather than those of the subalkaline rocks and, at the same time, tends to concentrate the mineralizers.

Of special agents suggested by the composition of the alkaline rocks, and of some of their accessory minerals, chlorine is indicated as having played a leading part, with sulphur, as SO_2 ,

* S. Arrhenius: *Zur Physik der Vulkanismus*, Geol. Fören. Förh., xxii, p. 247, 1900.

less important. The strong affinity of chlorine for the alkali metals, particularly sodium, and related elements, its tendency to form with them mobile compounds, its presence in such minerals as sodalite and noselite, its emission from volcanoes, and its tendency, mentioned above, to be concentrated in the aqueous extract of magmas, are all suggestive facts in this connection. As to its quantitative sufficiency, Clarke* gives a percentage of 0.20 in his average composition of the lithosphere, ocean and atmosphere, as compared with 0.19 for carbon (including that in carbon dioxide). This chlorine is, of course, mostly in solution in sea water, and no adequate source has been found for it save in vulcanism.† In view of this fact and the well known chemical potency of the element, there is reason for ascribing to it a considerable part in the segregation of alkaline magmas.

The remarkable abundance of fluorite in certain gold telluride deposits associated with alkaline rocks suggests fluorine as, in some cases, an active agent in the development of the latter.

It need hardly be said that, throughout this paper, the term 'mineralizer' has been employed in the broad sense which has, of late years, become customary. Though not strictly in accord with earlier usage and, on this account, somewhat criticised,‡ such broad interpretation of the term is often, as in the present instance, very desirable.

To sum up briefly, in conclusion: The alkaline rocks, constituting only a small percentage of the igneous rocks of the earth, are regarded as ultimately derived from the practically universal subalkaline magma, and, from their relatively high content of rare elements and mineralizers, it is maintained that their differentiation has been largely effected through the agency of the latter.

In the derived alkaline magma there is a concentration of the agents effecting their separation and, thus, their differentiation is cumulative, leading to great diversity of composition, with fractions relatively rich in rare elements.

While the localization of the phenomena may be subject to mechanical control and have, in consequence, a tectonic expression, the nature of any such relation is not, at present, determinable.

The problem under consideration is of a large order of magnitude and of extreme complexity, but it is hoped that the foregoing suggestions may prove to be of some service in the effort to accomplish its final solution.

Princeton University, February, 1913.

* Op. cit., p. 33.

† Cf. Becker, G. F.: *The Age of the Earth*, Smithsonian Misc. Contrib., vol. lvi, No. 6, p. 8, 1910.

‡ Vogt, J. H. L., op. cit. p. 216.

ART. VI.—*On Solid Solution in Minerals. III. The Constant Composition of Albite*; by H. W. FOOTE and W. M. BRADLEY.

IN recent years, the fact is becoming more and more recognized that certain minerals are capable of taking up or dissolving, in solid solution, foreign components which from their nature can hardly be considered as isomorphous mixtures in the ordinary sense. Thus, the mineral pyrrhotite has recently been shown* to be a solid solution of sulphur in ferrous sulphide; nephelite always contains an excess of silica,† and analcite, of a hydrated silica.‡ It is impossible in most cases, with our present knowledge, to state with certainty the form in which the admixture occurs. The dissolved sulphur of pyrrhotite, for instance, may be as pyrite, the excess silica of nephelite may be as albite and the excess of hydrated silica in analcite as some other silicate, but in whatever form the admixture occurs, the solid solution is quite different in character from ordinary isomorphous replacement, such as is found in the feldspars where potash replaces soda.

Whether this capacity to form solid solutions with compounds of different type is fairly common among silicates or is limited to a few minerals can hardly be stated with certainty at present. This is chiefly due to the fact that most minerals have been chosen for analysis on account of their purity and freedom from mechanical admixture with other substances. If, however, a compound can dissolve another, it is evident that it will have taken up the maximum amount when it is found mixed mechanically with an excess of the substance dissolved. Thus, nephelite occurs with varying amounts of excess silica in solid solution, but it contains the maximum amount when it crystallizes with albite, which contains more silica than nephelite but the same proportions of soda and alumina. In order, then, to determine whether a mineral can form a solid solution with another, and to what extent this is possible, the composition of the mineral when associated with the other must be determined. If the composition remains fixed, independent of association, no solid solution takes place. If it changes with its association, then the maximum amount of solid solution can be determined.§

Albite sometimes occurs, associated with an excess of its

* Allen, Crenshaw and Johnston, this Journal, xxxiii, 169, 1912.

† Ibid., xxxi, 25, 1911. ‡ Ibid., xxxiii, 433, 1912.

§ This leaves out of account the possible effect of temperature on the maximum amount dissolved, but this is probably small under actual conditions of crystallization.

components, the latter either in the free condition, as corundum or silica, or in combination, as nephelite. These associations make it possible, as shown above, to determine with some definiteness whether solid solution occurs between albite and any of its components, and if so, to what extent. The mineral is such an important component of many rocks that it has seemed well worth while to investigate this problem.

Fortunately, excellent analyses of albite associated with quartz have already been made. These minerals occur together, beautifully crystallized, in a large pegmatite vein at Amelia Court House, Va., and an analysis of the albite was made by Musgrave under the direction of Prof. J. W. Mallett.* Another specimen from the same locality was analyzed by Robertson.† Specimens of albite from this locality in the Brush collection show quartz intimately associated with it, but in neither article was there any statement of the association. Professor Mallett, shortly before his death, however, wrote us as follows regarding the occurrence: "The albite you refer to occurs as a constituent of an extremely coarse-grained granite with abundance of quartz. The feldspar crystals are sometimes more than two feet long and there are sheets of mica twenty inches across." The analyses of this albite will be given below.

The occurrence of albite with corundum is much more uncommon. An analysis of this type of albite was published many years ago by Silliman.‡ The ratio between alkalies, alumina and silica was 1 : 1.16 : 6.04, which indicates a considerable excess of alumina above the theoretical ratio, but the analysis was made before heavy solutions were in use and the material was presumably not as pure as it is possible to obtain at present. On the other hand, Moroscewicz§ has shown that artificial fused mixtures of albite and anorthite, with excess of alumina, separate the latter as corundum on cooling, but his results hardly prove that some alumina in excess may not be retained in solid solution.

We have been able to obtain but one specimen of a rock containing both albite and corundum. This was a corundum-syenite from Brudenell, Renfrew Co., Canada, furnished us by Prof. L. V. Pirsson. It also contained nephelite. Preliminary tests showed that the albite contained calcium, indicating the presence of some anorthite in solid solution.

In preparing the sample for analysis, the rock was crushed and albite separated by hand as carefully as possible. It was then sifted to a uniform grain and put through a heavy solution. On account of their higher specific gravity, there was no difficulty whatever in separating the mica and corundum.

* Chem. News, xlii, 204, 1882

† Chem. News, 1, 208, 1884.

‡ This Journal, viii, 390, 1849.

§ Min. petr. Mitt., xviii, 1, 1898.

Nephelite, however, has nearly the same specific gravity as albite and could not be entirely separated from the latter by this means. The material obtained floated in heavy solution of sp. gr. 2·645 and sank at 2·626. To free the material completely from a very small amount of nephelite, it was boiled three times with dilute hydrochloric acid. The solution from the first treatment gelatinized when evaporated, showing the presence of nephelite, but nothing further was extracted. Under the microscope, no impurities could be detected in the purified material.

The usual precautions were observed in the analysis. Silica, after being weighed, was tested for alumina by evaporating with sulphuric and hydrofluoric acids, and alumina, after weighing, was dissolved in a bisulphate fusion to test for silica. Evaporations were made in platinum. Alkalies were determined by a Smith fusion. The analyses by Robertson, Musgrave, and our own are given in Table I.

TABLE I.
Analyses of Albite.

	1 Albite associated with quartz (Robertson)	2 Albite associated with quartz (Musgrave)	3 Albite associated with corundum and nephelite (Bradley)		
			A	B	Average
SiO ₂	67·06	68·44	63·82	63·90	63·86
Al ₂ O ₃	21·72	19·35	23·40	23·24	23·32
CaO	1·59	----	3·77	3·75	3·76
MgO	·03	----	----	----	----
Na ₂ O	10·01	11·67	9·15	9·24	9·20
K ₂ O	·39	·43	·15	·17	·16
H ₂ O	----	----	·25	·24	·24
	100·80	99·89	100·54	100·54	100·54

In calculating the ratios from these analyses, it is necessary to make allowance for anorthite in the two specimens containing lime. The ratios, with corrections, are given in Table II.

TABLE II.
Ratios calculated from the Analyses of Table I.

	1 Ratios for anorthite		2 Ratios for albite	3 Ratios for anorthite		Ratios for albite
SiO ₂	1·110	·056	1·133	1·057	·134	·923
Al ₂ O ₃	·212	·028	·189	·228	·067	·161
CaO	·028	·028		·067	·067	
Na ₂ O }	·165	·165	·192	·149		·149
K ₂ O }						

The albite ratios of Table II are recalculated on the basis $\text{SiO}_2 = 6.00$ in Table III.

TABLE III.

	1	2	3
	Albite associated with quartz	Albite associated with quartz	Albite associated with corundum and nephelite
SiO_2 -----	6.00	6.00	6.00
Al_2O_3 -----	1.04	1.00	1.04
$\text{Na}_2\text{O} + \text{K}_2\text{O}$	.93	1.02	.94

The ratios in Nos. 1 and 3 are practically identical, though the associations are at opposite extremes. They differ considerably less than Nos. 1 and 2, where the association in both cases was with quartz. In no case is the variation greater than is common in minerals, due to errors of analysis or slight impurities in the minerals themselves. It seems fair to conclude, therefore, that no solid solution of quartz, corundum or nephelite in albite occurs which is greater than the apparent variation in composition, due to the ordinary errors of analysis.

Chemical and Mineralogical Laboratories of the
Sheffield Scientific School of Yale University,
New Haven, Conn., April, 1913.

ART. VII—*Triplite from Eastern Nevada*; by FRANK L. HESS and W. F. HUNT.*

THE triplite described in this paper was found in specimens of tungsten ore sent to one of the writers (F. L. H.) by Mr. G. G. Sims, of Aurum, Nevada. As described by Mr. Sims, the locality is in the Reagan mining district, about the middle of the Kern Range, White Pine County, Nevada. The prospect from which the mineral was obtained is six miles from the Utah line, 25 miles east of Aurum and 50 miles north of Osceola.

The country rock is said to be granitic, but among the specimens received are graphitic schist and other highly metamorphosed rocks. Many dikes cut the older rocks and in general both dikes and veins run north and south, paralleling the range.

The association of minerals is unusual. The veins, as judged from Mr. Sims' description and specimens, are quartz carrying wolframite (which is possibly hübnerite), scheelite (very little), pyrite, chalcopyrite (very little), an argentiferous sulphide of bismuth and lead which is probably cosalite, native bismuth, a little sericite, and the triplite which forms the subject of this article. Part of the quartz is of crystalline clarity and has been mistaken for topaz. The triplite is in irregular masses, the largest of which are less than an inch in diameter.

The ensemble strongly suggests a vein of pegmatitic origin and also suggests a relationship to veins in the Deep Creek Mountains of Utah, lying about 15 miles east of and parallel to the Kern Range. Certain gold veins in the Deep Creek Mountains are thought by B. S. Butler† to be of pegmatitic origin, and in the Clifton district farther north in the same mountains and about 40 miles northeast of the Reagan district are scheelite-bearing pegmatites carrying numerous other minerals. Triplite itself can probably be accepted as an essentially pegmatitic mineral and its presence in a vein would seem to indicate that the vein was either a phase of a pegmatite or deposited from magmatic waters. All the analyses quoted in this paper are of specimens either from pegmatites or from veins closely related to pegmatites, among which are tin-bearing veins.

Not only is the Reagan district a new locality for this somewhat rare mineral, but the variety here represented is rather different from previously described types and a short description is deemed desirable.

* Published by permission of the Director of the United States Geological Survey.

† Personal communication.

Chemical properties.—As considerable material was at hand, by exercising some care in freeing the mineral from its associates four or five grams of the pure substance was easily obtained for a chemical examination. Qualitative tests having established the composition as essentially a manganese-fluo-phosphate, a quantitative analysis was undertaken to determine the particular species.

The fluorine was determined according to the Fresenius method, by which the silicon fluoride liberated by the action of concentrated sulphuric acid and silica is absorbed in a train of U-tubes containing, respectively, moistened pumice, soda lime, and calcium chloride. The phosphoric acid was weighed as magnesium pyrophosphate after previous precipitation as ammonium phosphomolybdate. The manganese was precipitated as NH_4MnPO_4 after dissolving the first precipitate of the oxide. The minor constituents, ferrous iron, calcium, and magnesium, were estimated in the usual manner. In the analysis, separate samples were taken for the individual determinations with the exception of calcium and magnesium. Ferric iron, water, and the alkalis were absent.

The results of the above methods gave:

				mol. ratio	
MnO ..	57.63	MnO	43.13	.608	} .712 = 3.17
FeO ..	1.68	FeO	1.68	.023	
CaO	2.86	CaO	2.86	.051	
MgO ..	1.21	MgO	1.21	.030	
P ₂ O ₅ ..	31.84	P ₂ O ₅	31.84	.224	.224 = 1.
F	7.77	MnF ₂ ...	19.00	.204	.204 = .91
<hr/>					
102.99		99.72			
-O=F ...	3.27				
<hr/>					
99.72					

Approximately in whole numbers 3 : 1 : 1 or $3\text{MnO} \cdot \text{P}_2\text{O}_5 \cdot \text{MnF}_2$. The deviation from the theoretical composition is probably due to the somewhat unsatisfactory fluorine determination, for with a slight increase in the fluorine there would result in the recalculated percentage a decrease in the MnO. The similarity of the derived formula to the one generally accepted for triplite is easily recognized. Reference to the literature, however, reveals a considerable variation in the composition of this mineral, as shown by the following table:*

* As some of the earlier analysts overlooked the fluorine, their analyses have not been included.

	P ₂ O ₅	FeO	MnO	CaO	MgO	F	Fe ₂ O ₃	SiO ₂	H ₂ O	Na ₂ O	K ₂ O	Al ₂ O ₃	Total
1.	30.33	41.42	23.25	----	----	6.00	----	----	----	----	----	----	101.00
2.	31.29	31.03	31.05	1.42	tr.	8.17	----	----	----	.52	.72	----	104.20
3.	33.85	26.98	30.00	2.20	3.05	8.10	----	----	----	----	tr.	----	104.18
4.	32.33	20.48	32.60	.80	1.33	6.96	3.40	.11	1.25	.98	.33	2.16	102.73
5.	32.05	18.43	35.23	2.10	4.46	8.72	2.38	.18	.10	.31	----	.37	104.33
6.	35.65	18.30	37.84	4.46	tr.	4.94	----	.13	----	----	----	----	101.32
7.	31.50	16.07	38.20	5.99	----	7.87	2.25	----	----	----	----	----	101.88
8.	32.17	7.69	54.14	1.80	----	7.53	----	----	.36	----	----	----	103.69
9.	31.84	1.68	57.63	2.86	1.21	7.77	----	----	----	----	----	----	102.99

1. Bodenmais (Zwieselite), Rammelsberg, *Min. Ch.*, p. 351, 1860.
2. Vienna, John C. v., *Verh. k. k. Geolog. R.-Anst.*, I, p. 336, 1900; *Zeit. Kryst.*, xxxvi, pp. 642-643.
3. Schlackenwald, v. Kobell, *J. pr. Ch.*, xcii, p. 390, 1864.
4. Skrupetorp, Hamberg, Axel, *Geol. Fören. i. Stockholm, Förhandl.*, xxvi, p. 77, 1904; *Neues Jahrb.*, ii, p. 189, 1905.
5. Lilla Elgsjöbrottet, Nordenskjöld, Ivar, *Geol. Fören. i. Stockholm, Förhandl.*, xxiv, p. 412, 1902.
- 6 and 7. Sierra de Córdoba. Stelzner and Siewert, *Min. Mitth. Tschermak*, pp. 227-230, 1873.
8. Branchville, Penfield, *Dana Syst. of Min.*, 6th ed., p. 778.
9. Reagan District, Nevada, W. F. Hunt, analyst.

If, in the above analyses, those constituents representing either adhering matrix or altered material intimately mixed with the triplite are disregarded, the greatest variation is to be found in the proportion of FeO to MnO. Inasmuch as the percentage of FeO varies from 41.42 to 1.68 with a corresponding increase in the MnO from 23.25 to 57.63, we have unquestionably isomorphous replacements of these elements in all proportions and the term triplite must be considered to include not only those phosphates of manganese high in iron, but likewise those in which the iron content is practically negligible. The material from Nevada would seem to represent the manganese end member of this iron-manganese series.

Blowpipe and physical properties.—Triplite is soluble in acids. Before the blowpipe it fuses readily to a black globule and becomes slightly magnetic, and gives a manganese reaction with the borax bead. The color of triplite given in texts as various shades of brown and black, seems to correspond to those varieties rich in FeO or those possessing considerable included and oxidized material; the mineral here described was apparently unaltered, possessed a vitreous luster and light salmon-pink color. Streak white. $H = 4 - 4\frac{1}{2}$. Cleavage in two directions, one very prominent. Sp. gr. 3.79.

Optical properties.—The material was entirely massive and the indices were determined by immersion in oils by E. S. Larsen as follows: $a = 1.650$ $\beta = 1.660$ $\gamma = 1.672$, all $\pm .005$. The birefringence is about .020. The optic axis emerges perpendicular to one of the cleavages. A very large optical angle is shown by the extremely slight curvature of the bar observed on this interference figure. Optically +, dispersion $\rho > \nu$. Under high magnification some of the fragments reveal dark colored rounded or fibrous aggregates of included material. Similar inclusions were reported by Lazarevic* in a brown variety and Stelzner† is of the opinion that the dark color of triplite is to be explained by the unusually large quantities of these inclusions. Whether or not this supposition is correct, in the Nevada material, which is apparently unaltered and contains a comparatively small number of inclusions, we have a variety which is not brown but salmon-pink in color.

* Centr. Min., 385, 1910. † Min. Mitth., 222, 1873.

ART. VIII.—*The Heat of Formation of the Oxides and Sulphides of Iron, Zinc and Cadmium, and Ninth Paper on the Heat of Combination of Acidic Oxides with Sodium Oxide*; by W. G. MIXTER.

[Contributions from the Sheffield Chemical Laboratory of Yale University.]

THERE is comparatively little known about the heat of formation of minerals and the anhydrous oxides and sulphides of the metals. The hydrated compounds have, however, been more fully investigated. The object of the work was the study of some minerals. Some other compounds were also investigated. Except in a few cases the only way known of finding the heat of formation of a mineral is by fusion with sodium peroxide. The method involves the heat effect of a mineral and its components reacting with the peroxide.

The Oxides of Iron.

The heat of formation of the oxides of iron has been determined in the present investigation by the sodium peroxide method, and that of the magnetic oxide by burning the metal in oxygen. Two lots of sodium peroxide were used, one of which gave with 1 gram of rhombic sulphur 5270° and the other 5240°, and hence different heat effects of sulphur are given in the tables of results. The peroxide was passed through a $\frac{1}{2}$ mm mesh and only the fine powder used, since it gives quicker combustion and consequently higher temperatures than the coarse powder. After completing a series of determinations, the work was repeated with new preparations except in case of ferrous oxide. For brevity both series are put together in the tables.

Iron.—The metal was obtained by heating ferrous oxalate gradually in hydrogen to a red heat. When cold it was passed through a $\frac{1}{4}$ mm mesh and heated again in hydrogen. The preparation is indicated as "A." The determination of iron as ferric oxide gave 99.9 per cent. The sample contained a trace of carbon. Preparation "B," containing 99.8 per cent of iron, was from the reduction of pulverulent ferric oxide by hydrogen. Both lots of iron were free from hydrogen and yielded no water when burned in oxygen.

In the following experiments "A" was used in 1, 2 and 3, and "B" in 4.

A little iron remained unburned in 3, hence the result is not included in the final value, 1719°. For 2 gram atoms of iron reacting with sodium peroxide it is $1719^\circ \times 111.68 = 192000^\circ$.

	1	2	3	4	
Iron	2·550	1·754	1·754	3·000	grms.
Sulphur	1·500	1·500	1·500	1·500	
Sodium peroxide	20·	19·	20·	22·	
Water equivalent of system	3080	3078	3188	4108	
Temperature interval	4·016	3·573	3·423	3·180°	
Heat effect	12369	10998	10912	13063°	
Heat effect of sulphur	— 7905	— 7905	— 7905	— 7860	
“ “ “ ignition wire	— 80	— 80	— 60	— 45	
	4384	3013	2947	5158	
Heat effect of 1 grm. Fe	1719	1718	1680	1719	

Ferric Oxide.—Ferric oxide was made by heating the hydroxide to a faint red. When cold it was pulverized and sifted. Each portion used was heated again to a dull red before weighing to drive off hygroscopic water. Further heating was found not to change the weight. All heating was in an electric furnace where there was no liability of reduction. The following table contains all of the calorimetric results with ferric oxide.

The fusions of 1 and 2 were dark colored and gave with cold water ferric hydroxide and red solutions containing sodium ferrate. From the water solution of 2 barium ferrate precipitated on adding barium chloride. The fusions 3 and 4 were black on top but white below, and the remaining were white throughout. The water solutions of all except the first two were white and free from iron, proof that ferrate was not formed. In 1 and 2, where the temperature due to the reactions was lower than in the others, both ferrate and ferrite were formed, and hence the results are without value. Of the remaining experiments the last three are to be regarded as better than 3 and 4, since larger amounts of ferric oxide and smaller quantities of sulphur were taken. The average of 5, 6 and 7 is 363°. For 1 gram molecule of ferric oxide combining with sodium oxide the result is 58000°.

Van Bemmelen and Klobbie* prepared sodium ferrite, $\text{Na}_2\text{Fe}_2\text{O}_4$, by heating a mixture of ferric oxide and sodium hydroxide. They found it to be slowly decomposed by water. Hilpert and Kohlmeyer† consider that calcium orthoferrite, $3\text{CaO} \cdot \text{Fe}_2\text{O}_3$, is formed at 1410°. It is not possible to decide whether orthosodium ferrite, Na_2FeO_3 , or meta ferrite,

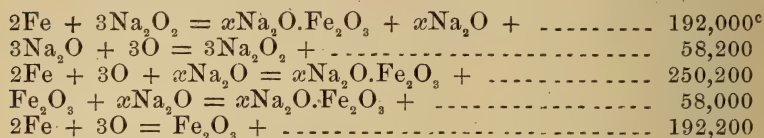
* J. Prac. Ch., xlv, 497, 1892.

† Ber d. deutsch. Chem. Gesell., xlii, 4581, 1909.

	1	2	3	4	5	6	7
Ferric oxide	8.410	9.495	3.429	3.530	5.403	5.115	5.296 grams
Sulphur	1.000	1.000	2.000	2.000	1.500	1.500	1.500
Sodium peroxide.....	20.	15.	26.	27.	20.	19.	20.
Water equivalent of system..	3978	3893	4028	4124	4112	4137	4149
Temperature interval	1.637	1.727	2.948	2.869	2.378	2.352	2.353°
Heat effect.....	6512	6723	11873	11833	9778	9730	9762 ^c
“ “ of S.....	-5270	-5270	-10480	-10480	-7860	-7860	-7860
“ “ “Fe wire.....	-50	-50	-40	-40	-45	-45	-45
“ “ “O ₂ set free +,							
absorbed —	+546	+481	not observed	-80	+80	+31	+82
Heat effect of Fe ₂ O ₃	1738	1884	1353	1233	1953	1856	1939
“ “ “1 gram of Fe ₂ O ₃	207	198	394	349	361	363	366

$\text{Na}_2\text{Fe}_2\text{O}_4$, is formed in the sodium peroxide fusions, but since the heat of the reaction of ferric oxide and sodium oxide is much greater than that of alumina and chromium sesquioxide, it is probable that sodium orthoferrite is formed. The formula $x\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3$ is used in equations to indicate that the composition of the ferrite is not known.

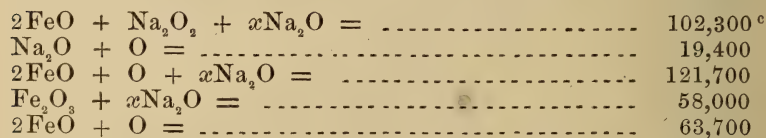
For the heat of formation of ferric oxide we have



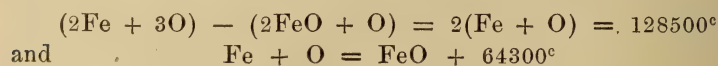
Ferrous Oxide.—The various products obtained by heating ferrous oxalate for the purpose of making ferrous oxide are described in a note on p. 68. The substance used in the following calorimetric work was a mixture of ferrous oxide and metallic iron, containing 16.27 per cent of the latter. It was free from carbon.

Substance (FeO 3.349, Fe 0.651).....	4.000	4.000 grams.
Sulphur	2.000	2.000
Sodium peroxide	26.	26.
Heat effect	14023°	14027°
“ “ of sulphur	10480	10480
“ “ of iron for ignition	40	40
“ “ of 0.651 grm. of Fe	1119	1119
“ “ of 3.349 grm. of FeO.....	2384	2388
“ “ of 1 grm. of FeO	712	713

For 2 gram molecules of ferrous oxide we have $712^\circ \times 143.68 = 102300^\circ$, and for the heat of oxidation the following:



and for the heat of formation of ferrous oxide



Ferrous Ferric Oxide.—Attempts to burn iron completely were not successful, hence the heat effect of oxygen taken up was found. The iron, preparation “B,” was placed in the hemispherical bottom of a steel bomb, which was then repeatedly exhausted and filled with dry oxygen, fairly free from nitrogen, and finally at a pressure of 12 to 15 atmospheres.

The ignition was by means of an iron wire heated by electricity. Most of the product of a combustion was in one button which contained a few cavities indicating dissociation of ferric oxide. The contents of the bomb were collected and weighed. Then it was washed and the few decigrams of dust collected were ignited and weighed. The experiments were as follows :

	1	2	3
Iron	8.105	8.499	8.609 grams
Product	11.202	11.676	11.757
Oxygen combined	3.097	3.177	1.148
Heat effect	12685	13167	13067°
“ “ of 1 grm.			
of oxygen	4096	4144	4150°

The average is 4125°. While the product of a combustion is a mixture of iron and oxides it is mostly ferrous ferric oxide as shown later. Moreover, the heat effect of an atom of oxygen in the different iron oxides is nearly the same. Hence the error is insignificant in the value derived for $3\text{Fe} + 4\text{O}$, which is $4125^\circ \times 64 = 264,000^\circ$ at constant volume and $265,200^\circ$ at constant pressure.

The products of the experiments were united, pulverized and sifted. About 0.2 gram of iron was picked out and a small portion of the substance remaining on the sieve contained metallic iron. The powder appeared to be free from metal, as it gave no gas when dissolved in hydrochloric acid. The iron in the powder, determined as ferric oxide, was found to be 72.14 and 72.07, mean 72.1 per cent; oxygen by difference 27.9 per cent. The corresponding formula is $\text{Fe}_3\text{O}_{4.05}$.

Magnetite.—Magnetite from a large crystal, excluding 0.27 per cent of silica, was found to have the following composition :

	I	II	Mean	Calculated for Fe_3O_4
Iron	72.74	[72.65]	72.7	72.36%
Oxygen	[27.36]	27.35	27.3	27.64%

The iron in I was determined as ferric oxide, and the oxygen in II by loss on heating 2.6481 grams of the substance in hydrogen. The mineral contained no aluminum, manganese, calcium or magnesium. The composition is expressed by the formula $\text{Fe}_3\text{O}_{3.94}$.

The calorimetric fusions were treated with water, and dilute nitric acid was added to dissolve the ferric hydroxide formed and the magnetite left was collected and weighed. The following are the results obtained with magnetite and the magnetic oxide described above :

Substance	Magnetite, $\text{Fe}_3\text{O}_{3.94}$		Magnetic Oxide, $\text{Fe}_3\text{O}_{4.05}$	
	5.161	6.056	5.615	5.910 grs.
" left	0.285	0.457	0.520	0.620
" combined (a) ..	4.876	5.599	5.095	5.290
Sulphur	1.500	1.500	1.500	1.500
Sodium peroxide	20.	20.	20.	20.
Heat effect	10104	10473	10087	10174°
" " of S	-7860	-7860	-7860	-7860
" " " Fe	-45	-45	-45	-45
" " " O_2 set free +	32	51	77	106
" " " a (b)	2231	2619	2259	2375
" " " 1 grm. $\frac{b}{a}$	457	468	443	449

The mean for the magnetite is 462° and for the magnetic oxide 446° .

For the oxidation of the magnetite we have $2\text{Fe}_3\text{O}_{3.94} + 1.12 \text{ O} = 3\text{Fe}_2\text{O}_3$. The mass of $2\text{Fe}_3\text{O}_{3.94}$ is, in terms of atomic weights, 461.12. The heat effect of $\text{Na}_2\text{O}_2 - \text{O}$ is $-19,400^\circ$ and of $1.12 \text{ O} - 21,700^\circ$, hence

$2\text{Fe}_3\text{O}_{3.94} + x\text{Na}_2\text{O}_2 =$	$462^\circ \times 461.12 =$	213,300°
$1.12 \text{ Na}_2\text{O} + 1.12 \text{ O} =$		21,700
$2\text{Fe}_3\text{O}_{3.94} + 1.12 \text{ O} + x\text{Na}_2\text{O} =$		235,000
$3\text{Fe}_2\text{O}_3 + x\text{Na}_2\text{O} =$		174,000
$2\text{Fe}_3\text{O}_{3.94} + 1.12 \text{ O} =$		61,000
$2\text{Fe}_3\text{O}_{3.94} + \text{O} =$	$61000 \div 1.12 =$	54,500

For the heat of union of ferrous with ferric oxide we have

$$(2\text{FeO} + \text{O}) - (2\text{Fe}_3\text{O}_4 + \text{O}) = 9,200^\circ$$

and for the heat of formation of magnetite

$$(2\text{Fe} + 3\text{O}) + (\text{Fe} + \text{O}) + (\text{FeO} + \text{Fe}_2\text{O}_3) = 265,700^\circ$$

From the heat of the reaction of fused magnetic oxide with sodium peroxide is derived $3\text{Fe} + 4\text{O} = 264,600^\circ$, which accords well with $265,200^\circ$, found by burning iron in oxygen.

The results of Berthelot* and LeChatelier† are included in the following summary :

	B.	LeC.
$\text{Fe} + \text{O} = \text{FeO}$ (900°)	+ 64,300§	64,600§
$2\text{Fe} + 3\text{O} = \text{Fe}_2\text{O}_3$ (faint red)	+ 192,200§	198,400§
$3\text{Fe} + 4\text{O} = \text{Fe}_3\text{O}_4$ (magnetite)	+ 265,700§	
$3\text{Fe} + 4\text{O} = \text{Fe}_3\text{O}_4$ (fused)	+ 265,200†	268,800§
$2\text{FeO} + \text{O} = \text{Fe}_2\text{O}_3$	+ 63,700§	65,200§
$2\text{Fe}_3\text{O}_4 + \text{O} = 3\text{Fe}_2\text{O}_3$	+ 54,500§	
$\text{FeO} + \text{Fe}_2\text{O}_3 = \text{Fe}_3\text{O}_4$ (magnetite)	+ 9,200§	
$\text{Fe}_2\text{O}_3 + x\text{Na}_2\text{O} = x\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3$	+ 58,000†	

* Ann. Chim. Phys. (5), xxiii, 118.

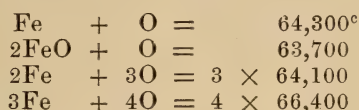
† C. R., cxx, 623.

‡ Experimental result.

§ Derived result.

Berthelot derived his result from the heat of solution of a readily soluble magnetic oxide in hydrochloric acid. LeChatelier burned in oxygen mixtures of ferrous oxide and carbon and of ferric oxide and carbon, and based his calculations on B's heat of formation of magnetic oxide.

The heat effect in the different stages of oxidation of one atom of oxygen is nearly the same, as LeChatelier observed, thus :



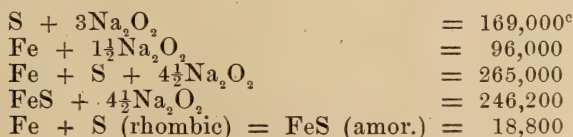
The figure for the last is higher than the others because of the considerable heat of combination of ferrous with ferric oxide. This heat effect confirms the view that magnetite is meta-ferrous ferrite.

After the foregoing work was finished the paper of Ruff and Gersten,* Ueber das Triferro-carbid, came to the writer's notice. In the investigation they obtained for the heat of formation of Fe_3O_4 $267,100^\circ \pm 200^\circ$ and FeO $60,400 \pm 1800^\circ$.

Ferrous Sulphide.—Allen, Crenshaw and Johnston† state that by heating iron in hydrogen sulphide an iron sulphide is formed, having approximately the composition of FeS . The writer's preparation, prepared by this process, contained 1·7 per cent excess of sulphur, equivalent to 3·2 per cent of FeS_2 . The following are the results :

Ferrous sulphide.....	3·308	3·502	3·698 grams
Sodium peroxide	20·	20·	20·
Water equiv. of system....	3110	3171	3170
Temperature interval	2·994	3·141	3·307°
Heat effect.....	9311	9960	10483°
“ “ of iron	50	50	50
“ “ “ FeS	9261	9910	10433
“ “ “ 1 gram FeS	2800	2830	2822

The mean is 2817° . Allowing for 0·032 gram of FeS_2 with a heat effect of 106° we have 2801° for 1 gram of ferrous sulphide, and for 1 gram molecule $246,200^\circ$. The heat of formation is derived as follows :



* Ber. d. Chem. Ges., xlv, 394.

† Zeit. f. Anorgan. Chem., lxxvi, 224.

Pyrite and Marcasite.—Pyrite from Danbury, Conn., was found to have very nearly the composition of $5\text{FeS}_2 + \text{FeS}$. Very likely the mineral had lost sulphur as dioxide when pulverized. The average of three combustions was 3241° and, allowing for ferrous sulphide present, 3321° for 1 gram of FeS_2 . At the time this result was not regarded as satisfactory because of the composition of the substance used. Hence another crystal of pyrite, locality unknown, was analyzed and also marcasite from Joplin, Mo., with the following results:

	Pyrite	Marcasite	Theory, FeS_2
Iron	47.1	47.1	46.54%
Sulphur.....	52.6	52.5	53.46%
Insoluble ...	0.1	0.2	---
	<hr/> 99.8	<hr/> 99.8	<hr/> 100.00

The results of the combustions were as follows:

	Pyrite		Marcasite.		
FeS_2	4.011	4.059	4.030	4.070	grms.
Sodium peroxide.....	24.	24.	27.	27.	
Water equiv. of system.	4045	4085	4147	4180	
Temperature interval...	3.301	3.316	3.233	3.251°	
Heat effect.....	13352	13545	13407	13589°	
“ “ of iron.....	—40	—50	—40	—40	
“ “ “ FeS_2	13312	13496	13367	13549	
“ “ of 1 grm.....	3318	3325	3317	3329	

The results indicate that the heat of formation of the two minerals is the same. Allen, Crenshaw and Johnston* find that pyrite is more stable than marcasite, and suggest that the latter may have a lower heat of formation than the former. In their paper† in the *Zeitschrift für Anorganische Chemie*, they notice that Carazzi‡ found the heat of combustion of pyrite and marcasite to be the same, namely, 1550° . If the two crystalline forms of iron disulphide differ as suggested the difference is small.

The average of the results obtained with sodium peroxide is 3322° . For the gram molecule it is $398,500^\circ$. From this number the heat of formation of FeS_2 is derived as follows:

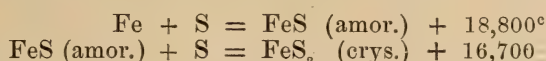
$\text{Fe} + 1\frac{1}{2}\text{Na}_2\text{O}_2$	96,000°
$2\text{S} + 6\text{Na}_2\text{O}_2 (5270 \times 32.07 \times 2)$	338,000°
$\text{Fe} + 2\text{S} + 7\frac{1}{2}\text{Na}_2\text{O}_2$	434,000
$\text{FeS}_2 + 7\frac{1}{2}\text{Na}_2\text{O}_2$	398,500
$\text{Fe} + 2\text{S} = \text{FeS}_2$ (crys.).....	35,500

* This Journal, xxxiii, 169.

† Loc. cit.

‡ Rend. Accad. Bolona, N. S., ii, 205, 1898.

For the heat effect of one and two atoms of sulphur we have



This accords with the oxides of iron where one atom of oxygen combining with iron produces but little more heat than when combining with ferrous oxide.

Zinc Sulphide.—The zinc blende was a honey yellow, translucent piece with brilliant cleavage planes. The zinc found in it was 67·10 per cent; theory 67·14 per cent. Zinc sulphide was prepared as follows: zinc oxide was heated gradually to a bright red heat in a current of dry hydrogen sulphide and allowed to cool in the gas. After pulverizing it was heated again in the gas to about 500°. A determination of zinc in this sulphide gave 67·19 per cent. Under the microscope a few bright surfaces were visible in the apparently amorphous powder. One would expect it to be crystalline since its heat of formation is the same as that of blende, and also because Deville and Troost* obtained crystalline zinc sulphide by heating the amorphous in hydrogen sulphide, probably hotter or longer than the writer did.

The fusions were treated with water and the zinc hydroxide formed was dissolved by acetic acid. The zinc sulphide left was collected and weighed.

The results are given on the following page.

The average of the results for the blende is 2005°. For the gram molecule it is 195,300°. The heat effect of $\text{Zn} + \text{S}$ is derived thus:

$\text{Zn} + \text{Na}_2\text{O}_2$	= 67,600†
$\text{S} + 3\text{Na}_2\text{O}_2$	= 169,000
$\text{Zn} + \text{S} + 4\text{Na}_2\text{O}_2$	= 236,600
$\text{ZnS} + 4\text{Na}_2\text{O}_2$	= 195,300
$\text{Zn} + \text{S (rhombic)} = \text{ZnS (crys.)}$	= 41,300

The average of the results for the zinc sulphide made is 1992°, which gives 42,500° for $\text{Zn} + \text{S}$. If we exclude the lowest result, 1970°, the mean of the other two is 2003° and we have 41,300°. Evidently the artificial sulphide has the same heat of formation as zinc blende.

Cadmium.—Cadmium chips which passed through a $\frac{1}{2}$ mm mesh were used in the work. An analysis of the sample gave Cd 99·96 per cent, Fe 0·005. The metal, as is well known, oxidizes slowly and superficially in ordinary air. In a desiccator, however, it remains bright. On page 65 are the data obtained from combustions with sodium peroxide.

* C. R., lii, 920, 1861.

† This Journal, xxx, 199.

	Zinc blende			Zinc Sulphide made		
	2·000	2·922	3·262	2·571	3·008	4·106 grams
Zinc sulphide	2·000	2·922	3·262	2·571	3·008	4·106 grams
“ “ not burned	0·042	0	0·025	0	0·092	0·014
“ “ burned (<i>a</i>)	1·958	2·922	3·237	2·571	2·916	4·092
Sulphur	0·500	0·500	0·500	0·300	0	0
Sodium peroxide	17	18	21	14	13	18
Water equivalent of system	3026	3065	3159	2963	2988	3060
Temperature interval	2·171	2·802	2·898	2·257	1·953	2·713°
Heat effect	6569	8588	9155	6687	5835	8302 ^c
“ “ of S	2635	2635	2635	1581	0	0
“ “ Fe	40	40	40	40	40	40
“ “ ZnS (<i>b</i>)	3894	5913	6480	5066	5795	8262
“ “ “ 1 gram ZnS $\frac{b}{a}$	1989	2024	2002	1970	1987	2019

Cadmium.....	5.000	6.002	4.000	grams
“ not burned	0317	1.329	0.106	
“ burned (a).....	4.683	4.673	3.894	
Sulphur	1.000	1.000	1.000	
Sodium peroxide	15.	18.	14.	
Water equivalent of system....	3.099	3.116	3.057	
Temperature interval	2.338	2.285	2.219°	
Heat effect.....	7247	7120	6783°	
“ “ of sulphur	5270	5270	5270	
“ “ “ iron	50	40	40	
“ “ “ Cd burned (b)....	1927	1810	1473	
“ “ “ 1 gram Cd $\frac{b}{a}$	411	387	378	

The difference between the highest and lowest result for 1 gram of cadmium is large, but this difference of 33° is, on the contrary, small when we consider the total heat effect of the experiments. The mean of the results is 392° and for 1 gram atom of cadmium reacting with sodium peroxide it is $392 \times 112.4 = 44,100^\circ$.

The fusions were yellow and it might be supposed that the color was due to a small quantity of cadmium sulphide. When, however, a mixture of cadmium and sodium peroxide was heated in a porcelain crucible, a yellow product resulted. The fusions in the bomb disintegrated slowly in cold water and gave off oxygen and yielded cadmium hydroxide. The latter was dissolved by cautiously adding hydrochloric acid and the metallic cadmium remaining was washed, dried and the weight of it deducted from the metal taken.

Very thin lathe turnings of cadmium for combustion in oxygen gained weight slowly in the air. It was found that 21.816 grams increased 2^{mg} in a few hours in the air and 2^{mg} more on standing 48 hours in a desiccator. These figures of course do not represent the total oxidation of the metal. The slight amount, however, does not affect the result, which is calculated from the weight of oxygen taken up by the metal when burned. The following method was used in the determination: Cotton was placed in the bottom of a 600°c bomb and a loose string of the cotton was drawn up so that it extended above the bulky bunch of turnings. The ignition was by means of a fine cotton thread attached to a wire connecting the electrodes. The object of placing the bulk of the cotton below the turnings was to blow the metal away from the cold bottom of the bomb. After a combustion the contents of the bomb were shaken out, collected in a crucible, warmed gently two or more times until the weight remained constant. Next the bomb was rinsed with water to remove the cadmium oxide

dust remaining. This was collected on a Gooch filter, heated and its weight added to that in the crucible. The following are the results:

Cadmium (<i>a</i>)	21.820	23.047	27.107	grams
Weight of product (<i>b</i>)	24.355	25.684	30.170	
“ “ O ₂ combined, <i>b</i> - <i>a</i> (<i>c</i>) ..	2.535	2.637	3.063	
Cotton	0.218	0.150	0.137	
Weight of O ₂ in bomb	8.5	10.5	11.	
Water equivalent of system	3656	3632	3635	
Temperature interval	2.951	3.053	3.600°	
Heat effect	10789	11088	13086°	
“ “ of cotton	882	606	544	
“ “ “ <i>c</i> (<i>d</i>)	9908	10482	12542	
“ “ “ 1 gram of O $\frac{d}{c}$..	3909	3975	4094	

Part of the product of a combustion was *reddish brown* cadmium oxide on the sides of the bomb and a considerable portion was a black sintered mass, fused on top and showing some crystals beneath. The atomic ratios of the cadmium taken to the oxygen combined are respectively 1.22, 1.25 and 1.26 to 1. That is, 1/5 of the cadmium had not burned. Free metal was not visible in the sintered mass, but the later left some metal when treated with hydrochloric acid. It is not probable that cadmium suboxide was present since it breaks up into oxide and metal when heated. For the effect of heat on cadmium oxide see note on p. 69.

The average heat effect of 1 gram of oxygen found is 3993° and for 1 gram atom combining with cadmium to form crystalline oxide and a little amorphous oxide the result is 63,900°.

Cadmium Oxide.—Cadmium carbonate was precipitated from a boiling solution of pure sulphate by a slight excess of sodium carbonate. It was washed, dried and heated to a bright red heat. The portion of the oxide taken for a calorimetric experiment was heated in a platinum crucible to redness. The crucible and contents were allowed to cool in a desiccator, weighed and the oxide at once transferred to the bomb.

The following are the results with cadmium oxide:

Cadmium oxide (<i>a</i>)	5.840	6.372	grams
Sulphur	2.344	2.095	
Sodium peroxide	27.	27.	
Water equivalent of system	4130	4232	
Temperature interval	3.057	2.677°	

Heat effect.....	12625	11329°
“ “ of sulphur.....	12282	10978
“ “ “ iron.....	30	40
“ “ “ cadmium oxide (<i>b</i>).....	313	311
“ “ “ 1 gram $\text{CdO} \frac{b}{a}$	53	49

While the results agree well they are to be regarded as approximations since the heat effect of the cadmium oxide is only 2·5 per cent of the total effect of the combustion. The mean is 51° and for one gram molecule of cadmium oxide it is $51 \times 128\cdot4 = 6548^\circ$.

Meunier* observed that cadmium oxide dissolved in molten sodium hydroxide, but failed to isolate the compound formed. The writer has found that the oxide did not dissolve if the hydroxide is first heated until free from water. When, however, a little water is added to the sodium hydroxide it dissolved cadmium oxide on heating. The fused mass was *white*. When treated with a very small quantity of water and filtered, the filtrate on dilution yielded a very little cadmium hydroxide. The fusions in the bomb were *yellow* and for reasons already stated the color is not due to cadmium sulphide. The difference in the condition of the two kinds of fusion may account for the difference in color. In the first case the reaction is with molten hydrated sodium hydroxide; in the second with sodium oxide at a high temperature. The writer found when a mixture of sodium peroxide and cadmium oxide was heated that oxygen came off freely and that the sintered mass left in water only reddish oxide and no white cadmium hydroxide. Evidently the temperature was not sufficient to effect combination of the two oxides.

Cadmium Sulphide.—Cadmium sulphide, precipitated by hydrogen sulphide from a hot solution of the sulphate, after washing and drying was heated to redness in a current of dry hydrogen sulphide and then left to cool in the gas. After pulverizing it was heated again as before. Cadmium found, 77·74 per cent: CdS has 77·80 per cent. Under the microscope it appeared as an amorphous powder containing a very few minute crystals. The following are the experimental data:

Cadmium sulphide.....	5·470	5·209	5·220 grams
Sulphur.....	0·0	0·500	0·500
Sodium peroxide.....	12·7	20·	20·
Water equivalent of system...	3942	3988	3984
Temperature interval.....	1·715	2·291	2·283°

* C. R., lxiii, 330.

Heat effect.....	6760	9136	9095°
“ “ of sulphur	0	2620	2620
“ “ “ iron	50	50	50
“ “ “ CdS	6710	6466	6425
“ “ “ 1 gram CdS....	1227	1241	1231

The average is 1233° for the heat of reaction of 1 gram of cadmium sulphide with sodium peroxide. For 1 gram molecule it is 178,100°.

For the heat of formation of cadmium sulphide we have

Cd + Na ₂ O ₂	= 44,100°
S + 3Na ₂ O ₂	= 168,000
Cd + S + 4Na ₂ O ₂	= 212,100
CdS + 4Na ₂ O ₂	= 178,100
Cd + S(rhombic) = CdS(crys.)	= 34,000

Summary.

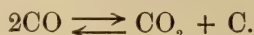
Cd + Na ₂ O ₂	= 44,100° *
Na ₂ O + O	= 19,400
Cd + O + Na ₂ O	= 63,500
CdO + Na ₂ O	= 6,500 * approx.
Cd + O = CdO(amor.)	= 57,000 † “
Cd + O = CdO(mostly crys.)	= 63,000 *
Cd + S(rhombic) = CdS(crys.)	= 34,000 †

Thomson found Cd, O, H₂O = 65,800°, and Cd, S, H₂O = 32,350°.

Note on Ferrous Oxide.

A quantity of ferrous oxide was needed and it appeared from the statements in Moissan's *Traité de Chimie* best to make it from ferrous oxalate. In the first attempt the oxalate was heated rapidly to a red heat in a bulb with a narrow neck, the end of which passed into water. After gas ceased to come off the neck was closed and the bulb allowed to cool. The product was found to have very nearly the per cent of iron in ferrous oxide. It was, however, a mixture of metallic iron, ferrous and ferric oxides and contained sufficient carbon to render it useless for the calorimetric work.

When ferrous oxalate is heated rapidly the reduction product first formed from the oxalate in contact with the hot sides of the containing vessel is exposed to the action of the oxides of carbon and water vapor from the decomposing oxalate. Under these conditions carbon separates, since, as is well known, carbon monoxide at 1000° dissociates thus :



To avoid separation of carbon or formation of iron carbide ferrous oxalate was heated in a current of pure dry nitrogen. The temperature was raised gradually and at the end of four

* Experimental result.

† Derived result.

hours was about 520° and carbon dioxide had ceased to come off. Then the temperature was raised to about 900° . At this temperature a very little carbon dioxide was given off. After an hour the bulb was sealed. The product was gray and dissolved in hydrochloric acid with evolution of hydrogen. It was free from carbon. A determination of iron as ferric oxide gave an atomic ratio, Fe 1.253 to O 1. The oxygen, determined by loss on heating the substance in hydrogen, gave a ratio of Fe 1.240 to O 1. The mean is 1.25 of iron to 1 of oxygen and hence Fe_5O_4 represents the composition of the substance. The atomic ratio very likely is adventitious and the substance should be regarded as a mixture of 4 molecules of ferrous oxide and 1 atom of iron. Such a mixture contains 16.27 per cent of metallic iron.

A number of investigators have described different ways of making ferrous oxide, but apparently no one has analyzed the product except Ruff and Gersten.* They tried to make it by passing a mixture of equal volumes of hydrogen and carbon dioxide over a mixture of equal parts of iron carbonate and ferrous oxalate at a red heat. They found that the product contained FeO , Fe_3O_4 , CO_2 (as FeCO_3) and amorphous carbon.

Note on the Volatilization of Cadmium Oxide.

The writer has observed that cadmium oxide loses weight at about 900° when heated in an electric furnace with platinum resistance. One experiment was made with the preparation described on p. 66. The weighed portion was in an unglazed porcelain crucible. The temperature at times was as high as the melting point of silver, 962° , but usually lower. The weight of the cadmium oxide after heating to redness and cooling in a desiccator was 3.050 grams. The weights observed after successive heatings were: 3.036, a few minutes; 3.029, time not noted; 3.025, 1 hr.; 3.016, 2 hrs.; 3.007, 3 hrs.; 3.001, 6 hrs.; 3.000, 4 hrs. The total loss was 1.66 per cent. The reddish brown oxide had changed to a black sintered mass showing some crystalline structure. About the top of the crucible was a reddish deposit.

In another experiment 28.088 grams of commercial cadmium oxide were heated successive times, in all 96 hours. The total loss was 0.641 gram, or 2.28 per cent. The temperature in this test was much of the time somewhat higher than it was in the first.

The results show that reddish brown amorphous cadmium oxide volatilizes or dissociates slowly at 900° to 1000° and that the rate of loss is less as the oxide becomes denser and crystalline.

Apparatus has not been available for the determination of the melting point or for the investigation of the vapor or dissociation pressure of cadmium oxide.

* Loc. cit.

ART. IX.—*A Deep Boring in Bermuda Island*; by L. V. PIRSSON and T. WAYLAND VAUGHAN.

IN April 1912 one of the writers (L. V. P.) was in Bermuda and lodging at the Princess Hotel. Through the courtesy of one of the managers, Mr. F. Howe, he learned that the hotel company had engaged in the project of putting down a deep well in the island in the hope of obtaining a more adequate water supply, and he was given the opportunity of seeing this well and of inspecting the material brought up from it. Later, owing to the kindness of Mr. Howe, he was furnished with a carefully taken and labelled set of samples, showing the character of the rocks at about every 40 feet in depth.

What process of reasoning or matter of experience led the projectors of this enterprise to hope to obtain a large supply of fresh water by boring into a conical mass, rising from the floor of the ocean's abyss, and whose summit alone projects into the region of any rainfall, it is difficult to conjecture. It may be said here, that the problem of a fresh-water supply in a thickly settled island like Bermuda, especially when needed in quantities in a large modern hotel, is a difficult one. In spite of its insular position the average rainfall is not high, running to two or three inches a month, with, generally, twice that quantity during some one month in the year. Springs and streams are a negligible quantity, while ordinary wells are poor, unreliable, and shunned for sanitary reasons. The ordinary supply is rain water, caught from the roofs of houses and stored in cisterns. Where a larger amount is needed, a sloping hillside is cleared of its vegetation and soil, down to the white chalk-like limestone, which having been cleaned and smoothed forms a watershed whose drainage is collected and led to the cistern. It is quite evident that no mere surface rainfall would supply any underground reservoirs in a small oceanic island like Bermuda, to be tapped by deep boring, and the projectors of the well realized this, but hoped that water of "volcanic origin" might in some way be met with. It is, perhaps, needless to say that this hope was not fulfilled.

But while the enterprise from the commercial side was a failure, its interest and value from the scientific standpoint is very great. Fortunately, it was perceived by Mr. Howe that this would be the case, and it was owing to his foresight that records were kept and samples taken at each stage of the work. One set of these has come into possession of the United States National Museum, and it is due to the courtesy and permission of Dr. Richard Rathbun, assistant secretary in charge,

that we have been given the opportunity of using this material in addition to our own.

Situation and Nature of the Boring.—The site of the boring is in the parish of Southampton, on the slope of a hill nearly a mile west of the lighthouse on Gibb's Hill. The spot selected is about 200 feet above sea-level. The method of boring was not that of the diamond drill by which a solid core is obtained, but by the use of a drill which is raised and dropped, a method commonly used in boring oil wells. In this case, the material is removed in the form of a coarse powder. Fortunately, in placing the casing, occasional chips of the rocks are broken off and obtained, and this has furnished some material of a size sufficient for the making of thin sections, and thus for petrographic study in the usual manner. At the time when the well was visited by one of us, the boring was down 800 feet; since then it has been continued over 600 feet more, making a total depth of over 1400 feet.

Summary of Results.—Very briefly stated for this preliminary paper, it may be said that of the 1400 feet penetrated by the boring, the first 360 feet are in the limestones of the usual character known in Bermuda. Below them for 200 feet, soft yellowish to brown, often clay-like rocks are met, whose nature indicates that they are more or less decomposed volcanic tuffs. Below them blackish to gray compact volcanic rocks are found, of andesitic and basaltic appearance. The study of the section made from a chip indicates that this is a lava, and, though considerably altered, an augite-andesite. This rock continues without essential change in character for the further 800 feet penetrated.

The geographical situation of Bermuda in the Atlantic basin, distant as it is from other islands and the continental mass, together with its isolation as a coral island, renders any new fact which we may obtain of its geology a matter of particular interest and value in several directions. The data which our investigation may be expected to furnish will have a bearing on the origin of coral islands and certain limestones; while a knowledge of the nature of the underlying lavas of the volcano will contribute material toward a better understanding of the problem of the distribution and relation of igneous rocks in the Atlantic basin. In addition, Mr. Joseph A. Cushman is studying the foraminifera for a report on the paleontology. The object of this paper is merely to give a preliminary notice of this investigation and of our being at work in this field.

New Haven and Washington, June 10th, 1913.

ART. X.—*A Note on the Preparation of Telluric Acid and a Test for Associated Tellurous Acid*; by PHILIP E. BROWNING and H. D. MINNIG.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccxlv.]

OF the various methods suggested for the preparation of telluric acid, two only seem to be in general use: first the oxidation of tellurous acid by chromic acid,* and the precipitation of the telluric acid by nitric acid after the concentration of the solution; and second, the oxidation of an alkali tellurite by hydrogen† dioxide, followed by the precipitation of the telluric acid by nitric acid. While both of these methods give quite satisfactory yields, the difficulty of washing out the chromium salt‡ in the first method, and of removing the alkali salt in the second method is apparent. Berzelius formed tellurates by passing chlorine into an alkaline solution of a tellurite, but here also the precipitation of the telluric acid would have the same disadvantage in the inclusion of alkali salts.

The work to be described was undertaken to study the effect of free chlorine upon elementary tellurium suspended in water. The element in the form of an amorphous powder weighing several grams was suspended in water and subjected to the action of a current of washed chlorine gas. After about an hour the tellurium had dissolved, and a portion of the solution, made alkaline and then acidified with acetic acid, remained clear, showing the complete oxidation to telluric acid.

It was found by experimentation with solutions of tellurates and tellurites that this method of testing would detect a milligram of tellurous acid in the presence of between one and two hundred milligrams of telluric acid, in a volume of 5^{cm}³.

When the solution was thoroughly saturated with chlorine and the complete oxidation was shown by this method of testing, the solution was evaporated to small volume, tested to be sure that no reduction had taken place, and again treated with chlorine if necessary. The concentrated solution was then treated with acetone or ethyl alcohol to the complete precipitation of a beautifully crystalline product of satisfactory yield. This product was washed with acetone or alcohol until the washings gave no test with silver nitrate for hydrochloric acid.

The telluric acid obtained was readily soluble in water; moreover, the solution gave no indication of the presence of tellurous acid on treatment with an alkali hydroxide and acetic acid, and was not reduced by stannous chloride except on warming.

* Staudenmaier, Zs. anorg. Chem. x, 189; Gutbier, xxix, 22.

† Gutbier, Zs. anorg. Chem., xl, 260.

‡ Kothner, A., cccxix, 39.

After concentration of the telluric acid solution, the acid may be precipitated by nitric acid, washed with the same reagent to remove the hydrochloric acid and then with acetone or ether to remove the nitric acid. This modification of the process, however, appeared to have no advantage in the purity of the product.

The absence of contaminating salts is practically assured by the method described if the elementary tellurium used is reasonably pure.

June, 1913.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *Compounds of Trivalent and Quadrivalent Tungsten.*—That tungsten forms compounds of at least one lower state of oxidation than tungstic acid, WO_3 , has been well known for a long time, as the beautiful blue color produced by its reduction has been extensively used as a qualitative test for the element, but heretofore little has been known in regard to the nature of the reduction products. O. OLSSON, however, has recently succeeded in preparing several well-crystallized compounds of trivalent and quadrivalent tungsten. By reducing strong hydrochloric acid solutions with metallic tin he obtained the double salts $\text{K}_2\text{W}_2\text{Cl}_6$ and $(\text{NH}_4)_3\text{W}_2\text{Cl}_6$, which show the existence of WCl_3 in combination. The analogous thallium, calcium and rubidium salts, $\text{Tl}_3\text{W}_2\text{Cl}_6$, $\text{Cs}_3\text{W}_2\text{Cl}_6$, and $\text{Rb}_3\text{W}_2\text{Cl}_6$ were prepared also. These salts are greenish yellow in color, they are fairly stable in the air in the dry solid condition, but in their preparation it was necessary to protect the solutions with an atmosphere of carbon dioxide. By using less complete reduction by means of tin the author has been able to obtain a single dark green salt, which appears to contain quadrivalent tungsten, with the formula $\text{K}_2\text{W}(\text{OH})\text{Cl}_5$. —*Berichte*, xlii, 566.

H. L. W.

2. *A New Oxide of Carbon.*—H. MEYER and K. STEINER have succeeded in preparing the anhydride, C_{12}O_9 , of mellitic acid. This is a benzol derivative, each of the six carbons of the benzol ring being combined with a CO group, and the three adjacent pairs of CO groups being connected by an oxygen atom. The compound is peculiar in containing precisely 50 per cent each of carbon and hydrogen. It forms brilliant, colorless crystals which are very stable, and may be dried at 160°C . without change. The substance begins to darken when heated above 320°C ., and it burns

with a smoky flame in the air, but it may be sublimed by heating in a vacuum. It is almost insoluble in cold water, but upon warming with water it forms mellitic acid, $C_{12}H_6O_{12}$.—*Berichte*, xlvii, 813. H. L. W.

3. *The Examination of Waters and Water Supplies*; by JOHN C. THRESH. Second Edition. 8vo, pp. 644. Philadelphia, 1913 (P. Blakiston's Son & Co. Price \$5.00 net).—This is an admirable treatise, dealing with all the aspects of the subject under conditions existing in England. The author emphasizes the importance of the examination of sources of water supply, and gives an excellent discussion of this topic. The methods of water examination are very fully treated, and the results of many analyses, useful for comparison, are given. There are 34 plates illustrating microscopical objects found in water. It may be mentioned that the author employs an ingenious and apparently novel device for eliminating the error due to the excess of the reagent necessary to produce the end-reaction in connection with certain volumetric determinations. For example, in determining hydrogen sulphide with centinormal iodine solution it was found that 500^{cc} of the water required 9^{cc} of the iodine solution to give a blue color with starch; then 8^{cc} more of the water itself removed the blue color. It was assumed that the true end-point lay half way between 500 and 508^{cc} of water, so that 504^{cc} was the amount used for the calculation. The same plan is used in determining chlorine by means of silver nitrate with a chromate as indicator. In a few operations the author recommends the use of weighed paper filters where the employment of the Gooch filter is to be preferred. H. L. W.

4. *Gas Analysis*; by L. M. DENNIS; 8vo, pp. 434. New York. 1913 (The Macmillan Company. Price \$2.10 net).—This very full and satisfactory text-book on gas analysis will be welcomed by all who are interested in teaching or practising this branch of analytical chemistry. In its general plan the book follows the author's well known translation of Hempel's work, but much new material has been added, and many of the older methods have been modified or omitted, so that the book is actually a new and original work. While the greater part of the book is devoted to rapid methods of technical gas analysis, descriptions are given also of certain methods of exact analysis that are adapted to specific determinations. The manipulation of the more generally used types of apparatus is very fully described, the illustrations are excellent, and in general the book deserves the highest praise. H. L. W.

5. *Chemical Analysis for Students of Medicine, Pharmacy, and Dentistry*; by ELBERT W. ROCKWOOD; 8vo, pp. 247. Philadelphia, 1913 (P. Blakiston's Son & Co.).—The fact that this is the fourth edition shows that the book is extensively used. After an introduction dealing with operations and a few general principles, a course of inorganic qualitative analysis is taken up, which is fairly extensive. Then comes a chapter on the qualita-

tive reactions of organic compounds, dealing with a number of substances important in medicine, including a few of the vegetable alkaloids. The second part of the book deals with volumetric analysis and gives a number of important methods. The last part takes up the sanitary examination of water, the detection of poisons, and blowpipe analysis. While some of the practical parts of the book are very brief, they appear to be well adapted to the purpose of serving as an introduction to the subjects. It would seem desirable to provide this class of students with some practice in gravimetric analysis, which is not included in this book.

H. L. W.

6. *Per-Acids and Their Salts*; by T. SLATER PRICE; 8vo, pp. 123. London, 1912 (Longmans, Green & Co.).—This is one of a series of "Monographs on Inorganic and Physical Chemistry," edited by Alexander Findlay. It deals very fully with an important branch of modern chemical research, gives very extensive references to the literature, and it is a very useful book for advanced students and for teachers of chemistry.

H. L. W.

7. *Practical Physiological Chemistry*; by PHILIP B. HAWK. Fourth Edition. Pp. xx, 475. Philadelphia, 1912 (P. Blakiston's Son & Co.).—The fourth edition of this useful manual of practical physiological chemistry has been greatly enlarged by the addition of much new material with a thorough revision of the old. Its usefulness has been greatly increased by the addition of references to the original literature, the lack of which in previous editions has limited its value as a reference book. The chapter on urine analysis contains a description of the newer methods such as Van Slyke's amino nitrogen method, and the microchemical methods of Folin and his coworkers for urea, ammonia, and total nitrogen. To the chapter on enzymes has been added a reference table of enzymes, their classification and properties. A description of the discovery, optical properties, and chief source of the amino acids occurring in proteins in tabular form has been added to the chapter on proteins. As in previous editions, the excellent illustrations are conspicuous. The book as a whole is admirably suited "for use in courses in practical physiological chemistry in schools of medicine and science," one-half of the contents being devoted to a study of the urine.

The main fault, if any, in this manual lies in too great a wealth of material rather than in too little. In the description of many of the various qualitative tests, it would seem that some selection of a few of the more important tests from among the many described, which vary only in some slight detail from each other, might well be made. The detailed description of some of the less important determinations such as the determination of fecal amylase and fecal bacteria should be relegated to more complete reference manuals. More space should be devoted to an account of the mode of origin of the aporrhegasms and other products of intestinal putrefaction, an account which in the present edition is limited to a statement of their primary source, proteins, with no more complete explanation.

H. B. L.

8. *The Influence of Dissolved Salts on the Absorption Bands of Water.*—Some important facts bearing on the theory of solutions have been discovered by H. C. JONES, J. S. GUY and E. J. SHAEFFER. The fundamental piece of apparatus used was a specially constructed radiomicrometer of short period. A Nernst glower produced the radiations. The region of wave-lengths investigated extended from 0.710μ to 1.445μ , since the infra-red absorption bands of water fall within this interval. The experimental method may be made clear by the following concrete example. The deflection of the radiomicrometer was observed when a chosen wave-length had passed through a cell containing a layer of solution 1^{mm} deep. Then the deflection was read when the same radiation had passed through a cell containing 11^{mm} of the same solution. The ratio of these two deflections measures, in a certain sense, the absorption which would be produced by a layer of the solution 10^{mm} thick. The object in using two depths was to eliminate the effects of the ends of the cells. Next the percentage by volume of water in the solution was calculated from the specific gravity of the solution and from its concentration. This percentage may be formulated as $100s - 0.1km$ where s denotes specific gravity, k means the multiple of normal, and m stands for the molecular weight of the dissolved substance. This method of calculation assumes that the solvent and solvent are present in the solution quite independently of each other. If the specific gravity of a $6 \times$ normal solution of potassium chloride is 1.236 the per cent calculated would be 78.9, ($k = 6$, $m = 74.6$, $s = 1.236$). Consequently the cell was set at a depth of 1^{mm} , filled with pure water, and the deflection noted. Then the micrometer reading corresponding to a depth of 8.89^{mm} of pure water was taken. As before, the ratio of these two deflections is a measure of the absorption caused by a column of water 7.89^{mm} deep, that is, due to a column equivalent (on the assumption of independence of solvent and dissolved salt) to the water present in 10^{mm} of solution. For each salt studied two curves are plotted on the same diagram. The abscissæ are wave-lengths and the ordinates are proportional to the ratios of intensities as explained above. One curve pertains to pure water and the other corresponds to the aqueous solution. The dissolved substances were chosen so as to have no appreciable absorption in the region of the infra-red absorption bands of water. For the chlorides and nitrates of ammonium and potassium the curves for the solutions and for the equivalent depths of water were practically coincident. This means that the dissolved substance and the solvent are effectively independent in solution, so far as the absorption of light is concerned. On the other hand, when the salts dissolved were calcium chloride, or magnesium chloride, or aluminium sulphate the solutions were far more transparent than the equivalent depths of pure water. This experimental fact is very striking. The last three salts have been shown by Jones to be the most strongly hydrated substances known, hence the obvious

explanation is that a certain percentage of water molecules have formed complexes or "hydrates" with the dissolved salt and that only the remaining water molecules are free to absorb as they would do if no dissolved substance were present. There are, of course, other ways of explaining the important fact mentioned above.—*Amer. Chem. Jour.*, vol. xlix, April, 1913, p. 265.

H. S. U.

II. GEOLOGY AND NATURAL HISTORY.

1. *United States Geological Survey*; GEORGE OTIS SMITH, Director.—Recent publications of the Geological Survey are noted in the following list (continued from vol. xxxv, p. 329):

TOPOGRAPHIC ATLAS.—Fifty-nine sheets, including a large map of the island of Kauai, Hawaii.

FOLIOS.—No. 184. Kenova Folio: Kentucky—West Virginia—Ohio; by W. C. PHALEN. Pp. 16; 13 figs., one chart, 3 maps.

No. 186. Apishapa Folio: Colorado; by GEORGE W. STOSE. —Pp. 12; 20 figs., 3 maps, 13 pls.

MINERAL RESOURCES of the United States, Calendar Year, 1911. Part I. Metals. Pp. 1018; 16 figs.

BULLETINS.—No. 502. The Eagle River Region, Southeastern Alaska; by ADOLPH KNOFF. Pp. 61; 5 pls., 3 figs.

No. 503. Iron-Ore Deposits of the Eagle Mountains, California; by EDMUND C. HARDER. Pp. 81; 13 pls., 4 figs.

No. 527. Ore Deposits of the Helena Mining Region, Montana; by ADOLPH KNOFF. Pp. 143; 7 pls., 4 figs.

No. 529. The Enrichment of Sulphide Ores; by WILLIAM H. EMMONS. Pp. 260.

No. 537. The Classification of the Public Lands; by GEORGE OTIS SMITH and others. Pp. 197; 8 figs.

WATER SUPPLY PAPERS.—No. 297. Gazetteer of Surface Waters of California. Part III. Pacific Coast and Great Basin Streams. Prepared under the direction of JOHN C. HOYT, by B. D. WOOD. Pp. 244.

No. 300. Water Resources of California. Part III. Stream Measurements in the Great Basin and Pacific Coast River Basins. Prepared under the direction of JOHN C. HOYT, by H. D. MCGLASHAN and H. J. DEAN. Pp. 956; 4 pls.

No. 310. Surface Water Supply of the United States 1911. Part X. The Great Basin. Prepared under the direction of M. O. LEIGHTON; by F. F. HENSHAW, H. D. MCGLASHAN, and E. A. PORTER. Pp. 210; 4 pls.

No. 313. Water Powers of the Cascade Range. Part II. Cowlitz, Nisqually, Puyallup, White, Green, and Cedar Drainage Basins; by FRED F. HENSHAW and GLENN L. PARKER. Pp. 170; 16 pls., 12 figs.

No. 316. Geology and Water Resources of a portion of South-Central Washington; by GERALD A. WARING. Pp. 46; one plate, one fig.

No. 317. *Geology and Underground Waters of the Wichita Region, North Central Texas*; by C. H. GORDON. Pp. 88; 2 plates.

A disastrous fire in the basement of the Geological Survey building, on May 18, destroyed most of the "reserve stock" of the Survey publications and some of the folios and topographic maps; the total loss is estimated at \$75,000. Fortunately a recent transfer to the Government Printing Office saved a large part of the publications from destruction and thus prevented a much larger loss. A new fireproof building, to cost about \$2,500,000, is in prospect, but unfortunate delays in Congress have postponed the beginning of the construction for another year.

2. *Bureau of Mines, United States*.—Recent publications include the following (see vol. xxxv, p. 330):

BULLETINS.—No. 48. *Selection of explosives used in engineering and mining operations*; by CLARENCE HALL and S. P. HOWELL. Pp. 50; 3 pls., 7 figs.

No. 52. *Ignition of mine gases by the filaments of incandescent electric lamps*; by H. H. CLARK and L. C. ILSLEY. Pp. 31; 6 pls., 2 figs.

No. 54. *Foundry-cupola gases and temperatures*; by A. W. BELDEN. Pp. 29; 4 pls., 16 figs.

No. 55. *The commercial trend of the gas-producer in the United States*; by R. H. FERNALD. Pp. 92; 1 pl., 4 figs.

No. 62. *National Mine-Rescue and First-Aid Conference, Pittsburgh, Pa., September 23-26, 1912*; by H. M. WILSON. Pp. 74.

No. 63. *Sampling coal deliveries, and types of Government specifications for the purchase of coal*; by G. S. POPE. Pp. 68, 3 pls., 3 figs.

No. 65. *Oil and gas wells through workable coal beds; papers and discussions*; by G. S. RICE, O. P. HOOD, and others. Pp. 101, 1 pl.

Also Technical Papers, Nos. 14, 31, 36, 38, 40, 46, 48, 52, 53.

3. *Geological Survey of New Jersey*; HENRY B. KÜMMEL, State Geologist.—Bulletins 8 and 9 have recently appeared. No. 8 contains the annual administrative report of the State Geologist for 1912, and two Appendixes. The first appendix describes the improvements of Shark River Inlet as ordered by the legislature of May 1, 1911; this is by C. C. VERMEULE, Consulting Engineer. Appendix B gives a list of new bench marks in some eight counties.

Bulletin 9, compiled by ALANSON SKINNER and MAX SCHRA-BISCH, is a preliminary report of the archæological survey of the State. The first chapter describes the types of Indian remains found in New Jersey, and the following chapters the Indian camp sites and rock shelters in different parts of the State. A map accompanies the report, showing the distribution of archæological remains.

4. *Map of West Virginia, showing Coal, Oil, Gas, Iron Ore and Limestone Areas*; published by the West Virginia Geological Survey and the State Semi-Centennial Commission; I. C. WHITE, State Geologist, assisted by RAY V. HENNEN and C. E. KREBS. Morgantown, W. Va., 1913.—This new edition contains a thorough revision of the coal, oil, and gas developments, several anticlinals being added, and others corrected from later observations. The valuable iron ore deposits of the State are also indicated on this map, and all the special features of previous editions corrected and brought up to date, showing the approximate areas of the several coal series, operating mines and their post office addresses, as well as the oil and gas pools. Scale, 8 miles to the inch. Price by mail, 50 cents each.

5. *West Virginia Geological Survey*; I. C. WHITE, State Geologist. Volume V (A), *The Living and Fossil Flora of West Virginia*. Pp. xiii, 491. Wheeling, 1913.—This volume consists of two parts. Part I, *The Living Flora*, by Dr. C. F. MILLSPAUGH. This is a complete revision of the "West Virginia Flora" published in 1896, with many additions and new species brought up to date. It is invaluable for students and teachers of Botany. Also Part II, *the Fossil Flora*, by Dr. DAVID WHITE. A complete list of the fossil plants associated with each of the great coal beds, thus constituting a much-needed guide to correlation.

6. *Wisconsin Geological and Natural History Survey*. E. A. BIRGE, Director; W. O. HOTCHKISS, State Geologist.—An important map of the State of Wisconsin has recently been issued showing both the Geology and Roads. This has been prepared by W. O. Hotchkiss and F. T. Thwaites and is issued in two parts on a scale of 6 miles to the inch. It is based upon the work of the present Survey, that of 1873-9 under T. C. Chamberlin and of other organizations. A concise outline of the geological history of Wisconsin is added in the second sheet, which gives also three structure sections.

7. *Geological Survey of Alabama*; EUGENE ALLEN SMITH, State Geologist. *Iron-making in Alabama*. Third edition; by W. B. PHILLIPS. Pp. 254; 31 pls. 2 figs.—This is the third edition of a work first published in 1896. The years that have elapsed since then have seen very great advance in the production of iron ores, and the manufacture of iron and steel, in Alabama. This whole subject is presented in detail, with a large number of interesting plates.

There has also been issued: *Map of the Coosa Coal Field with vertical and horizontal sections*; by WILLIAM F. PROUTY, Assistant State Geologist.

8. *Canada Department of Mines*.—Recent publications of the Canada Department of Mines (see vol. xxxv, p. 550) are as follows:

(1) GEOLOGICAL SURVEY BRANCH; R. W. BROCK, Director.

MEMOIRS. No. 17, E.—*Geology and Economic Resources of the Larder Lake District, Ontario: and adjoining portions of*

Pontiac County, Que.; by MORLEY E. WILSON. Pp. vii, 62; 11 pls., 5 figs., 2 maps.

No. 35. Reconnaissance along the National Transcontinental Railway in Southern Quebec; by JOHN A. DRESSER. Pp. vii, 42; 6 pls., 3 figs.

(2) MINES BRANCH; EUGENE HAANEL, Director.

An Investigation of the Coals of Canada with reference to their Economic Qualities. In six volumes; by J. B. PORTER and R. J. DURLEY, with assistants. Vol. V, pp. 318, 17 charts; vol. VI, pp. 120; 3 pls., 6 figs.

Annual Report on the Mineral Production of Canada during the Calendar Year 1911. JOHN McLEISH, Chief of the Division of Mineral Resources and Statistics. Pp. 316.

The Magnetic Iron Sands of Natashkwan, Saguenay, Quebec; by G. C. MACKENZIE. Pp. 49; 22 pls., 9 figs., 3 maps.

BULLETIN, No. 8.—Investigation of Peat Bogs and Peat Industry of Canada, 1910–11; by A. ANREP. Pp. 53; 19 pls., 1 fig.; 12 maps in separate pocket.

9. *Virginia Geological Survey*; T. L. WATSON, Director. Bulletin No. V, *The Underground Water Resources of the Coastal Plain Province of Virginia*; by SAMUEL SANFORD (prepared in coöperation with U. S. Geol. Survey). Pp. 361, figs. 8, tables 11, map in pocket. Charlottesville, 1913.—Bulletin No. V forms a companion volume to the previously published "Physiography and Geology of the Coastal Plains Province of Virginia" (this Jour., xxxiii, 594), 1912, and deals exhaustively with the underground water problems of this portion of the coastal plain. Plenty of water is to be had in this area and the position and character of the Cretaceous, Tertiary and Pleistocene beds are so well known that the depth required to secure artesian flows can be determined within fairly narrow limits. Following a general discussion of principles and recommendations regarding well construction, sanitation, etc., the ground water conditions in thirty-eight counties included within the area are treated in detail,—a most commendable feature, since the report is designed to be of direct use to farmers and municipalities. The tables of well data (pp. 297–353) furnish a convenient summary. In the opinion of the reviewer there is no better expression of the economic value of geologic science than is to be found in the volumes issued by the Federal and State Surveys dealing with water resources.

H. E. G.

10. *Geological Survey of Ohio*; J. A. BOWNOCKER, State Geologist. *Fourth Series, Bulletin 14* (in coöperation with the United States Geological Survey), *Geology of the Columbus Quadrangle*. Part I, Historical or Areal Geology, by CLINTON R. STAUFFER, pp. 11–50; Part II, Physiography or Surficial Geology, by GEORGE D. HUBBARD, pp. 51–112; Part III, Economic Geology, by J. A. BOWNOCKER, pp. 113–129. Plates i–xxviii, figures 16, 3 maps in pocket.—The Ohio geological reports have taken high rank, particularly along stratigraphic and

economic lines, since the establishment of the first Survey. The publications, however, have been of limited use to teachers, students, and general readers because of their technical character. The present volume is designed for students in colleges and teachers in schools and admirably fulfils its purpose. The physiographic treatment in particular is adapted to serve as a textbook in itself. It is to be hoped that more volumes of this character will be forthcoming.

H. E. G.

11. *State Geological Survey of Wyoming, Bulletin 3, Series B, The Douglas Oil Field, Converse County; The Muddy Creek Oil Field, Carbon County*, by C. E. JAMISON, State Geologist. Pp. 50, pls. i-viii. Cheyenne, 1912.—In the Douglas anticline, the exposed beds exhibit a stratigraphic sequence from pre-Cambrian to Quaternary. Oil occurs in the Lower Cretaceous and most of the seventy-one wells sunk in this field report "small amount of oil." In the Muddy Creek field oil-saturated sandstone (lower part of Wasatch formation) overlies unconformably 3200-3400 feet of Fort Union sandstones and shales containing numerous beds of coal.

H. E. G.

12. *Coal, and the Prevention of Explosions and Fires in Mines*; by JOHN HARGER. Pp. 183. London, 1913 (Longmans, Green & Co.).—The character of this admirably written volume and its evident field of usefulness is sufficiently indicated by its contents. The principal chapters deal with: Combustion, respiration, mechanism of explosions, the rôle of dust in explosions, prevention of explosions, gob fires—their phenomena and treatment.

H. E. G.

13. *New Zealand Department of Mines, Geological Survey Branch*; P. G. MORGAN, Director. *Bulletin No. 15 (New Series), The Geology of the Waihi-Tairua Subdivision. Hauraki Division*; by JAMES MACKINTOSH BELL and COLIN FRASER. Pp. 192, pls. i-x, 10 diagrams, 18 maps and sections. Wellington, 1912.—The publication of maps and descriptions of the Waihi-Tairua subdivision completes the geological survey of the Hauraki peninsula,—an area prevailingly volcanic. No sedimentary formations occur in the region under discussion, the succession being: Eocene (?), andesitic and dacitic lavas and breccias; Miocene, similar to Eocene; Pliocene, rhyolitic and dacitic tuffs, breccias, agglomerates and flows. Dikes of andesite, dacite and rhyolite of post-Pliocene and earlier dates traverse the rock complex. Mineralization through hydrothermal action is especially pronounced in the Eocene and Miocene rocks. Attention is called to the similarity in origin and occurrence between the gold deposits of Hauraki and those of Washoe, Cripple Creek, Tonopah, etc., in the United States. Detailed discussion of mines and prospects, illustrated by analyses and maps, constitutes the major part of the report. The region has produced over \$50,000,000 worth of gold and silver bullion from quartz veins.

H. E. G.

14. *Geology and Ore Deposits of the Monarch and Tomichi Districts, Colorado*; by R. D. CRAWFORD. Pp. 317, 25 pls., 15 figs. Bulletin 4, Colorado Geological Survey, 1913.—The area described in this bulletin is situated in the southwestern portion of Chaffee County and the adjacent southeastern portion of Gunnison County, the Monarch District lying on the eastern and the Tomichi District on the western slope of the Sawatch Mountain Range. The region is one of high relief, ranging from an altitude of 6000 feet to the summit of Shavano Mountain, 14,239 feet. The pre-Cambrian rocks include gneisses and schists into which a granite batholith is intruded. These rocks were exposed to erosion for a long period and after the land surface was reduced to almost a peneplain there followed a period of subsidence and the deposition of a series of sedimentary rocks. Sedimentation was interrupted from time to time by periods of elevation and erosion. The important sedimentary rocks are a late Cambrian quartzite, an Ordovician limestone, a parting quartzite, an Upper Devonian limestone, a black dolomite of Mississippian time and Upper Carboniferous shales and sandstones. Following this period of sedimentation the region was subjected to strong compressive forces which threw the strata into a series of anticlines and synclines and developed many faults. Probably in Tertiary time much of the region now occupied by the Sawatch Range was invaded by a huge batholith of quartz monzonite whose southern limits are within this area. This intrusion was preceded and followed by intrusions of granular rocks in stocks and by minor intrusions of porphyry.

The ore deposits were formed probably immediately after and as a consequence of the intrusion of the quartz monzonite. The first discovery of ore in the Monarch District was in 1878. The various mines have produced since then approximately \$10,000,000 worth of ore. The deposits are of various types, including: (1) Replacement deposits in limestone, (2) filling of fault fissures in the sedimentary rocks with replacement of the wall rocks, (3) fissure veins in igneous rocks, (4) contact deposits. The greater part of the ores have been silver-bearing lead carbonate. Lead, gold and zinc have also been produced. The Tomichi District was discovered in 1879. Its ores have produced gold, silver, lead, zinc, copper and iron in commercial quantity, silver and lead being, however, by far the most important. W. E. F.

15. *The Devonian and Mississippian formations of northeastern Ohio*; by CHARLES S. PROSSER. Geological Survey of Ohio, J. A. BOWNOCKER, State Geologist. Fourth series, Bull. 15, 574 pp., 33 pls., 1 text fig., 1912.—The author here describes in great detail and with their essential fossils the many sections of the uppermost Devonian and basal Mississippian formations of northeastern Ohio and northwestern Pennsylvania. It is the work of many years, done between professorial duties. The writer for the present holds that the black shales of the Huron, Cleveland and Bedford, when traced eastward through Ohio, change into

the more fossiliferous Chagrin formation with its distinctly Chemung fauna. The difference in sedimentation is thought to be due to distance from the shore line. Therefore all of these formations appear to be more naturally referred to the Devonian period, while the Mississippian is begun with the Berea of Ohio and the Cussewago of Pennsylvania. The contact of these upper sandstones upon the underlying shales is often an irregular erosion line and is always disconformable. A number of brachiopods are described in detail, and much valuable paleontologic work is scattered throughout the work.

The volume is a most important contribution toward the final adjustment of the Devono-Carboniferous line of separation, which has been under discussion more or less vigorously for the past thirty-five years. C. S.

16. *Fossil Coleoptera from the Wilson Ranch near Florissant, Colorado*; by H. F. WICKHAM. State University of Iowa, Bull., Vol. vi, No. 4, 29 pp., 7 pls., 1913.—In this pamphlet are described five new genera (*Creniphilites*, *Cychramites*, *Protoncideres*, *Pythoceropsis*, *Xyleborites*) and forty new species. The author states that the Florissant strata have now yielded 377 species of described beetles, but that about 200 new forms still await description. All of these are derived from Miocene deposits of an area nine miles long and two miles wide, with a maximum thickness of fifty feet. In a quarry twenty feet long and six feet deep the author collected ninety-five species. He says, however: "It may be worth mentioning that a stroll along the beach of Lake Superior after a favorable night wind would show a much more striking assemblage of beetles, as far as size and structure are concerned, than seems to have been present about the shores of the ancient Lake Florissant" (6). C. S.

17. *The Lower Siluric shales of the Mohawk valley*; by RUDOLF RUEDEMANN. N. Y. State Museum Bull. No. 162, 151 pp., 10 pls., 30 text figs., 1912.—A most valuable and interesting study showing how the Trenton limestone in passing eastward into the Hudson valley changes into a shale (the Canajoharie and Schenectady formations) with markedly different faunal assemblages. The Utica and Frankfort formations are shown to be absent in the Hudson valley, though the latter formation is in part represented in the east by the Indian Ladder formation, deposited in a different trough, a long and narrow one belonging with the Green Mountain foldings. Verily, the supposedly reliable New York "Standard of Correlation" is hardly yet trustworthy!

As the distinguishing of these various faunas depends upon an accurate knowledge of the combinations of known forms and new species, the author here describes essentially all of the previously undefined or poorly understood forms, more than fifty in number. A new genus of marine alga is also proposed, *Sphenophycus*. C. S.

18. *An Introduction to Zoology, with Directions for Practical Work (Invertebrates)*; by ROSALIE LULHAM. Pp. xv, 457, with 328 figures and 5 plates by V. G. Sheffield. London, 1913 (Mac-Millan and Co.).—The recent trend of biological teaching away from anatomical details and toward a return to the Natural History studies which characterized the science a half century ago is well illustrated by this new book, prepared for use in British schools. The Introduction consists of a well-written and well-illustrated account of the external structure and habits of British invertebrate animals, with anatomical descriptions sufficient only for an understanding of the general structural plan of the different groups.

The subject matter is divided into twenty-seven chapters, each of which takes up for discussion a single group of animals. At the end of each chapter is a brief survey of the classification of the principal animal forms belonging to the group under discussion, with directions for their collection and study. The writer wisely selects for description the forms of common occurrence or popular interest. The marine forms receive less attention than those of the lakes and fields; 243 pages, or more than half the book, are devoted to the insects. The majority of the illustrations were drawn especially for this work and are of distinct merit.

W. R. C.

19. *Malaria, Cause and Control*; by WILLIAM B. HERMS. Pp. xi, 163, with 39 figures. New York, 1913 (The Macmillan Co.).—This is a practical guide to the control of one of the deadliest enemies of the human race, the malarial mosquito. The writer has had wide experience in the conduct of public campaigns against this pest, and gives here the methods which he has found most successful in protecting the individual and the community from its attacks. The economic importance of the malarial parasite, its life history and means of transmission, the different kinds of mosquitoes, essentials of control, results accomplished by public crusades, advice as to the management of mosquito campaigns, expenses involved, and desired legislation are some of the practical features which comprise the various chapters. This book will furnish the information necessary for the guidance of public health officers in this most important sanitary problem.

W. R. C.

20. *Publications of the British Museum of Natural History*.—The following important volumes, based upon the collections in the British Museum, have recently been issued :

The History of the Collections contained in the Natural History Departments of the British Museum, Vol. II. Appendix. By DR. ALBERT GÜNTHER. Pp. ix, 109.—This appendix to the second volume of the history of the Museum collections gives a record of the development of the zoological section from 1856 to 1895, when the author retired. Previous to the earlier date, this section had been recognized simply as a "Branch" of the Natural History Department of the originally undivided British Museum.

Thirty years ago, however, in 1882-83, the collections were removed to the new building at South Kensington, where they are now preserved. The total number of specimens increased from about 1,000,000 in 1868 to 2,245,000 in 1895. Much information of special interest to those concerned with museum administration is given in this volume.

Catalogue of the Mammals of Western Europe (Europe exclusive of Russia); by GERRIT S. MILLER. Pp. xv, 1019; 213 figures.—In the preparation of this catalogue, the Museum has been so fortunate as to have the services of Mr. Gerrit S. Miller, of the U. S. National Museum at Washington. He, as earlier noted (June No., p. 642), has already published a similar work on North American Land Mammals. The European collection of land mammals in the British Museum consists of about 5,000 specimens, of which 124 are types. It has been chiefly brought together during the past thirty years, and the sources from which material has been derived are noted in the introduction. Free use has been made of the specimens in other museums, so that the total number on which the work is based approximates to 11,500.

Catalogue of the Collection of Birds' Eggs. Vol. V. *Carinatae* (Passeriformes completed). By W. R. OGILVIE-GRANT. Pp. xxiii, 547; 22 plates.—With this volume the catalogue of birds' eggs is brought to a conclusion. Its appearance has been delayed through the unfortunate death of Dr. R. Bowdler Sharpe at the end of 1909. It concludes the order Passeriformes of the sub-class *Carinatae*.

Catalogue of the Lepidoptera *Phalænæ*, Vol. XII. Catalogue of the *Noctuidæ*; by SIR GEORGE F. HAMPSON. Pp. vi, 626; 134 figures.—The earlier volumes of this work have been repeatedly noticed in this Journal. In the present volume 63 genera and 648 species of the *Catocalinæ* are represented. The remainder of this sub-family, with two other small sub-families, will appear in volume XIII, in which the key to the genera and the phylogeny will be reprinted. The Atlas, embracing plates 192-221 to illustrate the above volume, is about to be issued.

Catalogue of the *Chætopoda*. A. *Polychæta*: Part I.—*Arenicolidæ*. By J. H. ASHWORTH. Pp. xii, 162; 68 figures, 15 plates.—An introductory survey of the history and classification of the *Chætopoda*, and in particular of the *Polychæta*, is introduced in this volume, which is especially devoted to the *Arenicolidæ*. No definite provision for the continuation of the volumes on the *Chætopoda* has been thus far made, but it is anticipated that the work now begun by Dr. Ashworth will be continued from time to time.

Catalogue of the Heads and Horns of Indian Big Game bequeathed by A. O. Hume, C.B.; by R. LYDEKKER. Pp. xvi, 45; 16 figures and portrait.—The present catalogue describes what are stated to be the finest specimens of the heads of the big game of India ever brought together; they were bequeathed to

the British Museum by Mr. Hume. He had earlier given an important series of Indian mammals, and also some thirty years ago a collection of skins and the eggs of birds from the Indian Empire, aggregating about 82,000 specimens.

A Revision of the Ichneumonidæ with descriptions of new genera and species. Part II. Tribes Rhyssides, Echthromorphides, Anomalides and Paniscides; by CLAUDE MORLEY. Pp. viii, 140; one plate.—This is a continuation of the revision commenced by the author in 1912.

21. *Annual Report of the Director of the Field Museum of Natural History*, FREDERICK J. V. SKIFF, to the Board of Trustees for the year 1912. Pp. 184–273. Plates XXXI–XLI. Chicago, 1913.—Dr. Skiff's report of the Field Museum shows the rapid work there being accomplished in the way of installations in ethnology and zoology. Some of the last, including large bird and animal groups, of very attractive character, are illustrated in the present pamphlet. The most important field work in anthropology was that of the Joseph N. Field expedition to Melonesia in charge of Dr. A. B. Lewis; this is in its fourth year and has yielded a large amount of valuable material. Numerous contributions, particularly in paleontology and botany, are also noted. The Museum appeals largely to the people of Chicago, and an increased attendance in 1912 of some 15,000 is remarked upon. The total amount expended in the direct work of the Museum was about \$240,000.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *General Index to the Chemical News, Vols. 1 to 100*. Pp. 712. London, 1913 (Chemical News Office).—More than fifty-three years have elapsed since the Chemical News was established by Sir William Crookes, the first number bearing the date Dec. 10, 1859. Since that time, it has appeared regularly as a weekly periodical. The current volume is the one-hundred and eighth and a total of about 2800 numbers have been issued. It is hardly necessary to remark upon the very large amount of original matter which has found publication in this valuable journal; in addition, each number has contained a résumé of the progress in chemistry and allied sciences, particularly on the industrial side, with notices of books and important memoirs. It is interesting that the name of the gifted veteran chemist should still appear as editor, while Mr. Walter S. Crookes is manager.

A great service has been now performed for the active chemist in making this mass of material easily accessible through a general index. This index embraces volumes 1 to 100 (1859–1909) and occupies more than 700 pages, closely printed in fine type, and arranged in three columns to the page. It is evident that no pains have been spared to make this work as complete and accurate as possible. The decision has been wisely reached to

include the subject matter and authors' index in a single vocabulary. Various methods have been employed to insure the maximum degree of conciseness, as in printing the titles belonging to a single subject in one paragraph, clearness being attained by the use of heavy-faced type for the volume number. Other points may be noted, thus references to the different ACIDS are brought together under the single word, sub-divided, as far as practicable; upwards of twenty pages are required for this portion of the work. The titles of reviews and notices of books are also grouped together under "BOOKS," which cover some thirty-six pages; in addition, the author's name in each case appears in the vocabulary independently. Numerous cross references have been inserted which will insure a prompt finding of the subject desired. All those interested, particularly in chemistry and chemical industry, will be grateful to the management of Chemical News for bringing to completion this great work.

2. *The Journal of Ecology*; edited for the British Ecological Society by FRANK CAVERS. Vol. I, No. 1, May 5, 1913 (Cambridge University Press).—The plan of the new Journal is thus stated by A. G. Tansley: "The aim of the Journal of Ecology is twofold. In the first place, as the organ of the British Ecological Society, it will endeavor to foster and promote in all ways the study of ecology in these islands. In the second place it will endeavor to present, by critical articles and reviews, by full notices of recent ecological publications, and by full lists of current ecological literature, a record of and commentary on the progress of ecology throughout the world." The editor adds further, that contributions (in English, French, or German) are invited; preference will as a rule be given to short articles and notes (not exceeding about 2000 words) and those with a general ecological bearing. Editorial communications should be addressed to Dr. Cavers, Goldsmiths' College, London, S. E.; subscriptions should be sent to the Manager, Cambridge University Press, Fetter Lane, London, E. C.

The articles in this first number are, as follows: Some remarks on Blakeney Point, Norfolk; by F. W. Oliver. Raunkiaer's "Life-Forms" and statistical methods; by William G. Smith. A universal classification of Plant-Communities; by A. G. Tansley. Also the briefer articles: The relation of the present plant population of the British Isles to the glacial period; by Clement Reid. The nature reserve movement in Great Britain; by Wilfred M. Webb. In addition, pages 47-78 are given to a series of notices in part general but chiefly on work bearing on British and on foreign vegetation.

3. *Annual Report of the Superintendent of the Coast and Geodetic Survey*, O. H. TITTMANN, for the Fiscal Year ended June 30, 1912. Pp. 106; 10 illustrations including pocket maps. Washington, 1913.—This report with its atlas and series of maps gives the usual summary of the progress of the Survey for the year ending June 30, 1912. Several parties were engaged in the

interior states and territories on primary and secondary triangulation. Magnetic observations were made at five observatories, in addition to which there were six parties engaged in this work on land, and observations were also made by the Survey vessels at sea. In this way the magnetic elements were determined at upward of 300 stations, while 60 stations were reoccupied for the purpose of determining the secular change of the elements. The international boundaries between the United States and Canada and between Alaska and Canada have also made important progress.

The Superintendent has also published a report to the seventeenth General Conference of the International Geodetic Association on the geodetic operations in the United States, 1909-1912.

The California-Washington Arc of Primary Triangulation; by A. L. BALDWIN. Special Publication No. 13. Pp. 78; 7 illustrations.

4. *Hurricanes of the West Indies*. Prepared, under direction of WILLIS L. MOORE, by OLIVER L. FASSIG. Pp. 28; 4 tables, 25 plates. Washington, 1913. U. S. Department of Agriculture, Weather Bureau Bulletin.—This important memoir discusses the areas and tracks of West Indian hurricanes; their frequency (88 per cent in August, September and October); progressive movement; duration and intensity; origin, and allied points. The storm of August 7-20, 1899, so destructive in Porto Rico, is described in particular detail. This general subject becomes of vital interest in connection with the development of navigation in West Indian waters likely to result from the opening of the Panama canal.

5. *Die Zersetzung und Haltbarmachung der Eier*; by Prof. Dr. ALEXANDER KOSSOWICZ. Pp. vi, 74. Wiesbaden, 1913 (J. F. Bergmann).—The monograph includes a detailed review of the literature relating to the occurrence of bacteria, yeasts, and moulds in eggs under various conditions of preservation, along with the author's experimental observations bearing on this question. In contrast with the contentions of certain American investigators he finds that fresh eggs rarely contain bacteria within them. However in the course of time micro-organisms readily find their way into the interior through the intact shell. This is particularly true of the putrefactive type. In discussing the problems of preserving eggs the author emphasizes low temperature, lime-containing mixtures, and water glass solutions. L. B. M.

6. *Publications of the Comitato Talassografico Italiano*, Venice, 1912.—The Commission for the investigation of the Italian Seas, which began its work in 1910 (see vol. xxxi, p. 581), continues to be highly active in its many departments. A bi-monthly bulletin is published, the last received being No. 20 for the months of November and December, 1912. In addition, a series of twenty memoirs have been given to the public dealing with a great variety of subjects. These include the temperature and composition of the sea water; meteorological conditions over the sea deter-

mined, for example, by balloons; the life of the sea, and the fisheries, as those for sponges on the African coast. A large amount of important material is thus being brought together, having to do with the Adriatic and Mediterranean.

7. *Publications of the Allegheny Observatory of the University of Pittsburgh*; edited by FRANK SCHLESINGER, Director. These include the following:

Volume II, Title Page and Contents.

Vol. III, No. 1. Irregularities in Atmospheric Refraction; by FRANK SCHLESINGER. Pp. 10.

No. 2. The Orbit of U. Sagittæ; by MARY FOWLER. Pp. 11-15.

No. 3. A Description of Eighteen Spectrograms of Nova Geminorum; by FRANK C. JORDAN. Pp. 17-22.

Description of the Mellon Spectrograph: A Correction. Pp. 197-199. Index, p. 199.

The addresses given in connection with the dedication of the new Allegheny Observatory on August 28th, 1912, are printed in a special pamphlet of 39 pages with 3 plates—Misc. Sci. Papers, N. S., vol. ii, No. 2.

8. *Publications of the Detroit Astronomical Observatory of the University of Michigan*; WILLIAM J. HUSSEY, Director. Volume I. Pp. 72; 13 plates. Ann Arbor, 1912.—This includes a general illustrated account of the Observatory by the Director; also papers on the single-prism spectrograph by R. H. CURTISS, and on the registration of earthquakes from Aug. 16, 1909 to Jan. 1, 1912, by W. M. MITCHELL.

9. *Carothers Observatory—private astronomical, Houston, Texas*.—Bulletin No. 1 discusses the "Central Law of the Weather;" localized "long range" forecasts in actual operation, a comparison with U. S. Weather Bureau's local forecasts; by W. F. CAROTHERS.

10. *Bibliotheca Zoologica II. Verzeichniss der Schriften über Zoologie Welche in den periodischen Werken Enthalten und vom Jahre 1861-1880 selbständig erschienen sind*, etc.; bearbeitet von Dr. O. TASCHENBERG. Achtzehnte Lieferung. 5515-5800. Leipzig, 1910 (Wilhelm Engelmann, Mittelstrasse 2).—The opening parts, I and II, of this valuable and exhaustive work were noticed in 1887 (see vol. xxxiii, p. 245). During the years that have elapsed, nineteen parts have been published, of which seventeen belong to the work proper in its different divisions. Part XVIII (as also XIX, vol. xxxv, p. 558), are supplementary in nature; the one now in hand contains corrections and additions, dealing first with literature, books, and periodicals, and, second, with the subjects of aquariums, museums, zoological gardens, laboratories and microscopes, and finally with works dealing with the history of natural sciences and allied subjects. The fact that the work as a whole has run to 6,000 pages, with from twenty to twenty-five references on each page, indicates its extraordinary completeness.

11. *Chemical and Biological Survey of the Waters of Illinois*. Report for year ending December 31, 1911. EDWARD BARTOW, Director. Pp. 173 ; 20 plates. University of Illinois Bulletin. Vol. 9, No. 20. Urbana, Illinois.—This report has much more than a local value, since the subject with which it deals is of vital importance to all communities situated on the banks of any one of our great rivers. The whole subject of stream pollution in its various aspects is taken up in detail, and much information is given as to the analytical work done, with special details as to individual localities.

12. *The Mining World Index of Current Literature, Vol. II. Second Half Year 1912*; by GEO. E. SISLEY, Associate Editor Mining and Engineering World. Pp. xxiv, 234. Chicago, 1913.—The Mining World Index, planned to cover the world's current literature in mining metallurgy and the allied industries, and since 1911 published weekly in the Mining and Engineering World, is now presented in book form, covering half a year; this second volume concludes 1912. The promptness of its appearance makes it particularly valuable to all immediately concerned with the field here covered.

OBITUARY.

DR. ERNST KITTL, the well-known Austrian paleontologist, died on May 1, 1913, at the age of 59 years. He was professor in the Royal Technical High School, and Paleontologist and Director of the Geological Department of the Royal Natural History Museum, Vienna. His work was especially along the lines of the faunas of Triassic time.

PROFESSOR JAMES GORDON MACGREGOR, of Edinburgh University, died on May 21 at the age of sixty-one years. He was born at Halifax, was graduated at Dalhousie College and had devoted himself with signal success to investigations in physics.

LORD AVEBURY, better known as Sir John Lubbock, died on May 28 at the age of seventy-nine years. Many readers have gained pleasure and inspiration from his able writings on flowers and insects.

DR. WILLIAM HALLOCK, professor of physics in Columbia University, died on May 21 in his fifty-sixth year. He was graduated at Columbia in 1879 and received the degree of Ph.D. from the University of Würzburg in 1881. From 1882-91, he was connected with the U. S. Geological Survey as physicist, and in this capacity did much important research work. He became associate professor of physics at Columbia in 1892, professor in 1902 and was dean of the Faculty of pure science from 1906 to 1909.

New Circulars.

- 84: **Eighth Mineral List:** A descriptive list of new arrivals, rare and showy minerals.
- 85: **Minerals for Sale by Weight:** Price list of minerals for blowpipe and laboratory work.
- 86: **Minerals and Rocks for Working Collections:** List of common minerals and rocks for study specimens; prices from 1½ cents up.
- Catalogue 26: Biological Supplies:** New illustrated price list of material for dissection; study and display specimens; special dissections; models, etc. *Sixth edition.*

Any or all of the above lists will be sent free on request. We are constantly acquiring new material and publishing new lists. It pays to be on our mailing list.

Ward's Natural Science Establishment

76-104 COLLEGE AVE.,

ROCHESTER, N. Y.

WARD'S NATURAL SCIENCE ESTABLISHMENT

A Supply-House for Scientific Material.

Founded 1862.

Incorporated 1890.

DEPARTMENTS:

Geology, including Phenomenal and Physiographic.

Mineralogy, including also Rocks, Meteorites, etc.

Palaeontology. *Archaeology and Ethnology.*

Invertebrates, including Biology, Conchology, etc.

Zoology, including Osteology and Taxidermy.

Human Anatomy, including Craniology, Odontology, etc.

Models, Plaster Casts and Wall-Charts in all departments.

Circulars in any department free on request; address

Ward's Natural Science Establishment,

76-104 College Ave., Rochester, New York, U. S. A.

CONTENTS.

	Page
ART. I.—Investigation of the Prehistoric Human Remains found near Cuzco, Peru, in 1911; by H. BINGHAM	1
II.—Vertebrate Remains in the Cuzco Gravels; by G. F. EATON	3
III.—Gravels at Cuzco, Peru; by H. E. GREGORY	15
IV.—Simple Model for Illustrating the Symmetry of Crystals; by A. H. PHILLIPS	30
V.—Chemical Composition of the Alkaline Rocks and its Significance as to their Origin; by C. H. SMYTH, Jr.	33
VI.—Solid Solution in Minerals. III. The Constant Composition of Albite; by H. W. FOOTE and W. M. BRADLEY	47
VII.—Triplite from Eastern Nevada; by F. L. HESS and W. F. HUNT	51
VIII.—Heat of Formation of the Oxides and Sulphides of Iron, Zinc and Cadmium, etc.; by W. G. MIXTER	55
IX.—Deep Boring in Bermuda Island; by L. V. PIRSSON and T. W. VAUGHAN	70
X.—Preparation of Telluric Acid and Test for Associated Tellurous Acid; by P. E. BROWNING and H. D. MINNIG	72

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Compounds of Trivalent and Quadrivalent Tungsten, O. OLSSON: New Oxide of Carbon, H. MEYER and K. STEINER, 73.—Examination of Waters and Water Supplies: Gas Analysis: Chemical Analysis for Students of Medicine, 74.—Per-Acids and their Salts: Practical Physiological Chemistry, 75.—Influence of Dissolved Salts on the Absorption Bands of Water, 76.

Geology and Natural History—United States Geological Survey, 77.—Bureau of Mines, United States: Geological Survey of New Jersey, 78.—Map of West Virginia, showing Coal, Oil, Gas, Iron Ore and Limestone Areas: Living and Fossil Flora of West Virginia: Wisconsin Geological and Natural History Survey: Iron making in Alabama: Canada Department of Mines, 79.—Underground Water Resources of the Coastal Plain Province of Virginia: Geology of the Columbus Quadrangle, 80.—State Geological Survey of Wyoming, Bulletin 3, Series B: Coal, and the Prevention of Explosions and Fires in Mines: New Zealand Department of Mines, 81.—Geology and Ore Deposits of the Monarch and Tomichi Districts: Devonian and Mississippian formations of N.E. Ohio, 82.—Fossil Coleoptera from the Wilson Ranch near Florissant, Col.: Lower Siluric shales of the Mohawk valley, 83.—Introduction to Zoology: Malaria, Cause and Control: Publications of the British Museum of Natural History, 84.—Annual Report of the Director of the Field Museum of Natural History, 86.

Miscellaneous Scientific Intelligence—General Index to the Chemical News, Vols. 1 to 100, 86.—Journal of Ecology: Annual Report of Superintendent of Coast and Geodetic Survey, 87.—Hurricanes of West Indies: Die Zersetzung und Haltbarmachung der Eier: Publications of Comitato Talassografico Italiano, 88.—Publications of Allegheny Observatory of University of Pittsburgh: Publications of Detroit Astronomical Observatory of the University of Michigan: Carothers Observatory: Bibliotheca Zoologica II, 89.—Chemical and Biological Survey of Waters of Illinois: Mining World Index of Current Literature, Vol. II, 90.

Obituary—E. KITTL: J. G. MACGREGOR: LORD AVEBURY: W. HALLOCK, 90.

Established by **BENJAMIN SILLIMAN** in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: **EDWARD S. DANA.**

ASSOCIATE EDITORS

PROFESSORS **GEORGE L. GOODALE**, **JOHN TROWBRIDGE**,
W. G. FARLOW AND **WM. M. DAVIS**, OF CAMBRIDGE,

PROFESSORS **ADDISON E. VERRILL**, **HORACE L. WELLS**,
LOUIS V. PIRSSON, **HERBERT E. GREGORY**
AND **HORACE S. UHLER**, OF NEW HAVEN,

PROFESSOR **HENRY S. WILLIAMS**, OF ITHACA,
PROFESSOR **JOSEPH S. AMES**, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

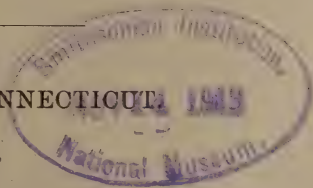
FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

No. 212—AUGUST, 1913.

NEW HAVEN, CONNECTICUT 1913

1913.



THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. \$6.40 to countries in the Postal Union; \$6.25 to Canada. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).

NEW DISCOVERIES AND NEW FINDS.

BEAVERITE, A NEW MINERAL.

This mineral, which was fully described in the December, 1911, number of this Journal, I have been fortunate enough to secure the whole output of. It was found at the Horn Silver Mine in Utah and is a hydrous sulphate of copper, lead and ferric iron. It was found at a depth of 1600 feet. In appearance it resembles Carnotite. Prices 75¢ to \$2.00.

PSEUDOMORPHS OF LIMONITE AFTER MARCASITE.

These remarkable Pseudomorphs, which have never before been found in such clear cut specimens, was described and illustrated in the last number of this Journal. I have secured the majority of the finest of these specimens. They vary in size from 2 inches to 6 inches. In color they run from brown to glossy black and they have met with favor from all who have seen them. Prices from \$1.00 to \$10.00.

CHIASTOLITES.

Of these remarkable specimens, which are generally known as lucky stones, I have secured the finest lot ever found at Madera Co., California. They are cut and polished and sold singly and in collections from 25¢ to 50¢ for single specimens; 9 specimens all marked differently for \$5.00, and 18 specimens, all different markings, for \$18.00. Matrix specimens, polished on one side showing many crystals, from \$2.00 to \$8.00.

SYNTHETIC GEMS.

It is remarkable the interest that has been taken by scientists in these wonderful scientific discoveries. The Corundums are now produced in Pigeon blood, Blue, Yellow, Pink and White. Also the new Indestructible Pearls in strings with gold clasps. These are identical in hardness and rival in color and lustre the real gems. They can be dropped and stepped on without injury and are not affected by acids. My collection of the above is unrivalled, and prices of the same are remarkably low.

OTHER INTERESTING DISCOVERIES AND NEW FINDS

Will be found in our new Catalogues. These consist of a Mineral Catalogue of 28 pages; a Catalogue of California Minerals with fine Colored Plates; a Gem Catalogue of 12 pages, with illustrations, and other pamphlets and lists. These will be sent free of charge on application.

Do not delay in sending for these catalogues, which will enable you to secure minerals, gems, etc., at prices about one-half what they can be secured for elsewhere.

ALBERT H. PETEREIT

261 West 71st St.,

New York City.

THE
AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XI.—*On the Velocities of Delta Rays*; by H. A.
BUMSTEAD.

§ 1.

THE name "delta rays" was given by Sir J. J. Thomson in 1905 to the slow electrons which he found to be emitted by polonium, and which had previously masked the positive charge of the α -rays. Shortly afterward, and independently, Rutherford discovered a similar emission from radium and showed that it was not confined to the source of α -rays, but took place from any body which was struck by them. Some writers have made a distinction between these two phenomena, restricting the name delta rays to those which are emitted by the source of α -rays and calling the others secondary rays. There appears, however, to be little ground for this distinction; there is no appreciable difference between the two kinds of rays, and everything goes to show that Rutherford was right in his original suggestion that all δ -rays are secondary phenomena, due to the impact of α -rays upon matter. In the present paper, therefore, the name will be used in this sense.

The question of the velocity of the δ -rays has been attacked by a number of investigators.* They have all agreed that a large proportion of the rays have velocities which are small, as electronic velocities go, not very different, in fact, from those which are observed in the photo-electric effect. The estimates by different observers of the maximum velocity of the rays have been discordant; they have varied from zero to $3.9 \times 10^8 \frac{\text{cm}}{\text{sec}}$, the latter corresponding to a fall of potential of about 42 volts.

*For a historical sketch of the subject see Campbell, *Jahrb. d. Radioaktivität und Elektronik*, ix, p. 419, 1912.

Last year it was shown by Dr. McGougan and the present writer* that electrons were present in a beam of δ -rays which had much greater velocities than any of the above estimates; an opposing potential difference of 1700 volts was not sufficient to stop all of them, and very marked effects were produced by electrons having velocities corresponding to several hundred volts. The present paper contains the results of some further experiments upon these swifter rays. It will be seen that there is no gap between the swifter and the slower electrons, but that all intermediate speeds are found between the highest and the lowest. It seems reasonable, therefore, to include under the name "delta rays" all the electrons which are projected from the atoms of bodies by the direct action of the α -rays, the recently discovered swift ones as well as the slower ones previously known; this nomenclature will be adopted in the present paper. It is, however, to be observed that some, at least, of the slower electrons (under 10 volts) must be caused, not directly by the α -rays, but by the swifter δ -rays. When there is occasion to refer to these they will be called *tertiary rays*. It is impossible at present to make a sharp distinction between the slower δ -rays and the tertiary rays which come from the source of δ -rays, or to determine the proportion of each; so that in all numerical estimates the tertiary rays must be included among the δ -rays.

§ 2.

Tertiary electrons are emitted also by any body on which δ -rays fall and in numbers considerably in excess of the swifter δ -electrons which cause them. When an electric field is used to hold back the slower δ -electrons, this is the most conspicuous effect of the remaining swift rays; for the field which opposes the δ -rays assists the tertiary electrons to escape, and their larger number magnifies the experimental effect. The unsuspected presence of this phenomenon has undoubtedly had an influence upon the results obtained in previous experiments upon δ -rays, and helps to explain the discrepancies which have appeared in the work of different investigators.

Unfortunately this effect, which is easy to observe and measure, does not lend itself readily to a quantitative study of the swifter δ -rays. The number of secondary electrons, due to a single incident electron, varies markedly, and not in a very simple way, with the speed of the latter.† In a beam of δ -rays one has a complex of electrons of many different speeds, and when the opposing electric field is, for example, increased, the

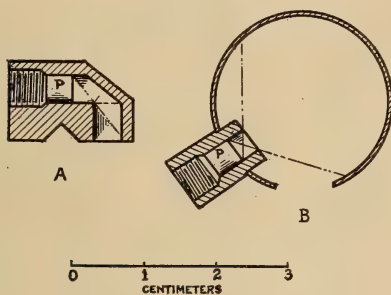
* Bumstead and McGougan, this Journal, xxxiv, 309, 1912; Phil. Mag., xxiv, 474, 1912.

† Gehrts, Ann. d. Phys., xxxvi, 1000 et seq., 1911.

slower of these are eliminated and all the remaining ones have their velocities reduced; under these circumstances it appears quite impossible to draw any conclusions as to the variation in the number of incident δ -rays from observations upon the tertiary electrons.

In attempting to determine the distribution in velocity of the swifter δ -rays, the essential thing, therefore, is to eliminate the effects due to the tertiary electrons. The first method by which I attempted to do this was to receive a beam of δ -rays in a Faraday cylinder, the whole arrangement being in a very high vacuum. Two different forms were tried for the source of the δ -rays; (A and B, fig. 1). In both of these the α -rays from

FIG. 1.



the polonium, P, struck the inner walls of a small brass chamber; a hole in this chamber was placed so as to allow some of the δ -rays to escape but none of the α -rays. The beam of δ -rays issuing from this hole was caught in a Faraday cylinder after passing through an opposing electric field; there were suitable diaphragms and earthed screens about the Faraday cylinder. But although I had in the neighborhood of a millicurie of polonium, the arrangement was not sensitive enough to do more than indicate the presence of the swifter rays, certainly not to measure them. Only a small fraction of the δ -rays generated in the chamber escaped through the hole, and, even so, the beam was so divergent that the Faraday cylinder had to be rather large ($5.5 \times 4^{\text{cm}}$); thus its electrostatic capacity was considerable and one could not gain any advantage by substituting a sensitive electroscope for the quadrant electrometer.

The next attempt was by insulating the source (either A or B) from the case and connecting it to the measuring instrument; as its capacity was small, an electroscope could now be used to advantage. A negative potential applied to the case would send back to the source all the electrons whose kinetic

energy was not sufficient to overcome the opposing potential difference. Here the difficulty was to prevent the tertiary electrons, set up by the impact of the δ -rays upon the case, from being carried to the source by the electric field. I first tried to obviate this by means of a magnetic field. A long cylindrical case was used (the one shown in fig. 2), with the source of δ -rays near the top and the rays striking the bottom and the lower part of the sides of the case. A magnetic field of about 50 gauss was applied to this part of the case. To prevent this field as much as possible from having an effect upon the emission of the δ -rays themselves, the source was inclosed in a sort of upper chamber made of a plate and a ring of soft Norway iron, 1.5^{cm} thick; (this is not shown in fig. 2). A tapered hole in the plate allowed the beam of δ -rays to pass into the lower chamber; both chambers were coated with soot. Preliminary measurements of the magnetic field in the upper chamber by means of a swinging needle showed that, with a field of 50 gauss near the bottom of the case, the field near the source was not more than 0.5 gauss.

This method was not wholly unsuccessful. In a charcoal vacuum which had been maintained for several days, the source lost negative electricity in the face of an opposing potential of 300 volts, but beyond that it acquired a negative charge. The form of the relation between current and potential for the lower voltages was quite similar to those obtained later with the final form of apparatus; with potentials over 250 volts, however, the effects of the tertiary electrons began to be conspicuous. Moreover, on account of the limited beam of δ -rays the values of the currents were small and necessitated the use of a very sensitive, and consequently troublesome, electro-scope.

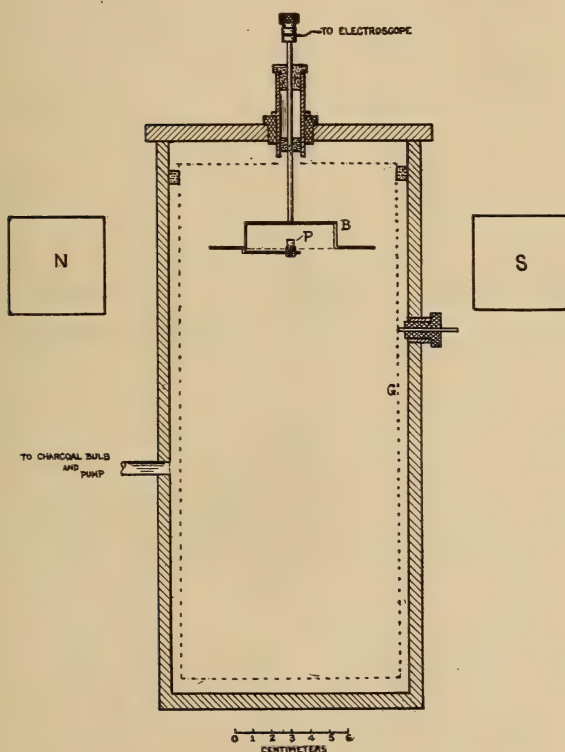
§ 3.

The final form of the apparatus is shown in fig. 2. The source of δ -rays is the shallow, open, cylindrical box, B, made of brass; in some of the later experiments, in which a magnetic field was used, the box was surrounded by a flat ring of brass, as shown in the figure, giving to the source the shape of a sailor's hat. Below, and opposite the middle of this box, a thin brass arm supported a cylindrical copper plug, P, with a deposit of polonium on its upper surface, which was 4^{mm} in diameter.* The end of this plug projected into the box so that none of the α -rays escaped, but fell upon the top and

*I am again indebted to Professor Boltwood for the polonium used in these experiments. For three successive years he has most kindly supplied me with the annual crop of polonium grown from a preparation of radio-lead in his possession.

sides of the box; the open character of the latter and the smallness of the obstacle presented by the polonium and its support enabled a large proportion of the δ -rays and tertiary rays to get away. This source was enclosed in a large, cylindrical brass case which could be highly exhausted by the help of charcoal and liquid air; the charcoal bulb was placed between the evacuated chamber and the pump and gauge, and

FIG. 2.



was so constructed as to free the chamber of mercury vapor by its distillation into the cold bulb. Within the case and $\frac{1}{2}$ cm from its walls was a cylindrical cage of bronze wire-gauze which was insulated from the case and could be separately charged by means of an external electrode. It was found to be important that the insulators supporting the cage should not be struck by the δ -rays; if they were, they acquired charges which gave rise to erratic results. Accordingly the cage was supported by three small pieces of ebonite near the

top, and out of the path of the δ -rays. The gauze had 5.5 meshes to the centimeter; of its entire area 83 per cent was open, the remaining 17 per cent was occupied by the wires.

The rod which supported the source, B, was insulated from the case and provided with an earthed guard-tube in the usual manner. It was connected to the gold-leaf of a sensitive electroscope of the Hankel type which has been previously described.* The magnitude of the effects obtained, even when all the slower δ -rays were stopped, was such that the electroscope could be used at the very moderate sensitiveness of 200 divisions per volt. Under these circumstances the deflections were strictly proportional both to potential and current over the whole range of the eye-piece scale in the microscope (100 divisions); the sensitiveness remained quite constant, so that there was no need of continual checking up by means of a potentiometer. When changes in the zero position occurred they were slow and steady and could easily be taken into account, and they caused no alteration in the sensitiveness; often the zero would not vary more than one or two divisions in an entire half-day's work.†

On account of the emission of δ - and tertiary rays, the source as soon as it is insulated acquires a positive charge which increases with the time. When there is no opposing field this charge is far too great to be measured with the arrangements described above. When the case and cage are both charged to the same negative potential, all the electrons, whose kinetic energy is less than the work which this potential can do upon an electron, are returned to the source and only the swifter ones escape; thus the rate at which the source acquires a positive charge is diminished. When, however, the negative potential applied to the gauze and case is more than about 25 volts, the source begins to acquire a *negative* charge, which (as the negative potential is increased) soon reaches a maximum and then steadily decreases; this continues up to, and beyond, 2000 volts. This effect has been shown to be due to the emission of tertiary electrons by the case when struck by the swifter δ -rays; the tertiary electrons are returned to the source of δ -rays by the field, and, as they exceed in number the δ -rays which produce them, the source acquires a resultant negative charge, which falls off, however, as more and more δ -electrons are restrained from reaching the case.‡

* Bumstead, this Journal, xxxii, 403, 1911; Phil. Mag., xxii, 910, 1911.

† In order to secure fair steadiness of the zero reading, it is necessary to protect any sensitive electroscope against sudden changes of temperature. With the electroscope mentioned, satisfactory protection is given by covering it with felt about $\frac{1}{4}$ inch thick, and by setting it up in a wooden box (with an open front), to keep off drafts in some degree. A glass window in the back of the box admits light to the gold-leaf.

‡ Bumstead and McGougan, l. c., § 3.

It was for the purpose of eliminating, if possible, this complication that the wire-gauze cage was introduced as a substitute for the magnetic field mentioned in § 2. Retarding fields may be set up by putting negative potentials on the gauze while the case is kept grounded. As the tertiary electrons have small velocities, those which are set up at the surface of the case, by the δ -electrons which have surmounted the field and passed through the meshes of the gauze, will not get back to the source on account of the field between the gauze and the case.* The electric force is much greater between gauze and case than between gauze and source, (though the potential difference is the same) because of the smaller distance; thus a considerable fraction of the tertiary electrons which originate on the wires of the gauze itself will be captured by this field and will not get to the source of δ -rays. As the case and source are always kept at zero while the potential of the gauze is changed, the *shape* of the lines of force, in the neighborhood of the wires of the gauze and within its meshes will not change, and it seems reasonable to assume that a nearly constant fraction of the tertiary rays originating upon the gauze will be captured in this way, and that the number which get back to the source in any case will be a small part of the total set up by the δ -rays on case and gauze together.

§ 4

With the case grounded and with various negative potentials on the gauze cage, readings of the electroscope gave the charge acquired by the source in a given time, usually one minute. It was soon evident that the readings thus obtained varied greatly with the time which had elapsed since the production of the vacuum. Three hours after the liquid air had been applied to the charcoal bulb, a negative potential of 40 volts on the gauze was sufficient to give a slight negative charge to the electrode (the source of δ -rays, B, fig. 2); and larger negative potentials caused a marked increase in this negative current. (See Curve I, fig. 3). As time went on, however, these effects were much altered; positive currents were observed with negative potentials on the gauze greater than 300 volts, and the negative currents at the higher potential were much diminished in magnitude. The results of four series of observations are given in Table I and shown graphically in fig. 3.

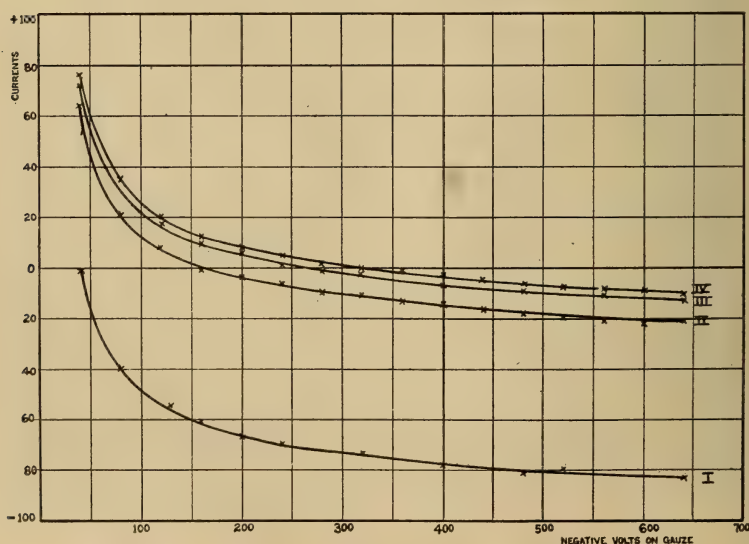
* This method has been several times used to prevent the reflection of slow electrons in experiments upon cathode rays and on the photo-electric effect. v. Baeyer, *Phys. Zeitschr.*, x, 174, 1909.

TABLE I.

Volts	I (3 hrs.)	II (22 hrs.)	III (46 hrs.)	IV (66 hrs.)	II-I	III-I	IV-I
- 40	- 0.3	+ 63.6	+ 72.7	+ 76.	63.9	73.	76.3
- 80	-39.7	+ 21.5	+ 33.	+ 34.5	61.2	72.7	74.2
-120	-54.7	+ 8.3	+ 18.	+ 20.5	63.0	72.7	75.2
-160	-61.3	+ 1.4	+ 10.	+ 13.5	62.7	71.3	74.8
-200	-67.5	- 3.5	+ 6.	+ 9.	64.0	73.5	76.5
-240	-70.	- 6.2	+ 1.7	+ 5.5	63.8	71.7	75.5
-280		-10.	- 1.0	+ 2.8			
-320	-74.	-10.7	- 2.8	0.	63.3	71.2	74.
-360		-13.4		- 1.			
-400	-78.4	-14.5	- 7.	- 3.	63.9	71.4	75.4
-440		-16.		- 4.			
-480	-82.2	-17.8	- 9.	- 6.	64.4	71.2	76.2
-520	-79.7	-19.6		- 7.	60.1		72.7
-560		-21.4	-11.	- 8.			
-600		-22.2		- 9.			
-640	-85.	-21.5	-13.2	-10.5	63.5	71.8	74.5

In the table, the first column gives the negative potentials applied to the gauze cage; the second, third, fourth, and fifth give the currents (in arbitrary units) observed at 3, 22, 46, and 66 hours, respectively, after the application of the liquid air; the remaining columns give the differences between these currents.

FIG. 3.



It will be observed that these differences are constant, and that the four curves of fig. 3 have the same form and are merely shifted vertically on the diagram. It is quite clear that we have here the resultant of two effects, the first independent of the time since the vacuum was made, and depending upon the applied potential, while the second is independent of the potential, but does vary greatly with the time. The first effect is plainly due (at least in great part) to the escape from the source, B, of the swifter δ -rays, thus giving it a positive charge, which is decreased as larger opposing potentials are applied to the gauze. The second phenomenon causes the source to gain negative, or to lose positive, electricity at a rate which is independent of the potential beyond 40 volts; and its variation with the time shows that it must be due to residual gas—either that which occupies the volume of the chamber, or that which is condensed upon its walls and on the electrode.

It seemed desirable first to investigate the nature and cause of the second effect. When the apparatus was in the condition which gave the upper curve (IV) in fig. 3, the liquid air was removed from the charcoal, and a small quantity of air admitted to the chamber so that the pressure rose to 0.2^{mm} . This was allowed to remain for about 15 minutes, when exhaustion was recommenced, while the charcoal bulb was heated in the usual manner. When the pressure had fallen to $.003^{\text{mm}}$, the liquid air was again applied. Three hours later a series of measurements was taken, the results of which were between those represented in Curves II and III, fig. 3. This shows that the effect in question is not due to a volume ionization of the residual gas. For the amount of gas in the chamber three hours after the application of the liquid air could not have been very different from that which was present when Curve I was taken. On the other hand, the surface films on the metals might well be different after a brief exposure to a pressure of 0.2^{mm} from what they were after a prolonged exposure to atmospheric pressure. In another experiment, air at atmospheric pressure was allowed to stand in the chamber for two days; upon re-exhaustion, the same behavior was observed as that shown in fig. 3. It seems clear therefore that the effect is due to the presence of surface films which are removed only very slowly in a high vacuum and probably not completely removed in any case.

The next question to be considered was whether the negative charge upon the electrode was due to electrons coming to it from the gas film on the case and gauze or to positive ions lost by the film on the electrode itself. To determine this a magnetic field was employed. The core of the magnet was a bar of soft iron 2 inches square in section, bent so as to form

three sides of a rectangle. One side of this rectangle, 21^{cm} long, was surrounded by the magnetizing coil; the other two sides, 18^{cm} long, embraced the case, as shown in fig. 2, and formed long, narrow pole pieces. Along these pole pieces, from their ends nearly to the magnetizing coil, the field was fairly uniform, not varying more than 10 per cent, when measured by a fluxmeter. In the other two directions at right angles to this, the variation of the field was rapid on account of the spreading out of the lines of force in the large air-gap. With a current of 5 amperes, for example, the field near either pole-piece was 530 gaussses, while half-way between them, and in their plane, it was 250. The field at any one point was nearly proportional to the current in the coil from 1 to 8 amperes. Before using the magnetic field, the brass box which served as the electrode and the source of δ -rays was provided with the brass ring shown in fig. 2 (forming the brim of the "hat"), which had not been present in the preceding experiments. Its purpose was to catch the δ -electrons, originating near one side of the box when they were bent by the magnetic field toward that side. The addition of this ring, by increasing the capacity of the electrode, decreased somewhat the readings of the electroscope.

With the magnetic field, the electrode charged up negatively, the rate reaching a maximum value with a current of 3 amperes on the magnet and not changing when the current was increased to 9 amperes. It was independent of the potential applied to the gauze from -40 volts to -1200, but it did vary with the time after the vacuum was made in the same manner as the results obtained previously. For example, with -40 volts on the gauze, and a magnetic field of 250 units, the following values of the current were obtained at different times after the application of the liquid air to the charcoal:

1 hour	-----	126	divisions	per	minute.
3 hours	-----	72	"	"	"
24 "	-----	25	"	"	"
48 "	-----	12	"	"	"
72 "	-----	9	"	"	"

We are, I think, justified in concluding that the carriers of this current are not electrons, but ions of atomic mass. Thus, in a magnetic field of 250 gaussses, an electron whose velocity was as great as that corresponding to 1600 volts would be curled into a circle of only half a centimeter radius, and could scarcely reach the electrode even if it started from the case with that velocity; and there is no evidence that any swift electrons start from the case at all. On the other hand, a

hydrogen ion whose velocity was due to a fall of potential of only 9 volts would move in a path whose radius of curvature is 1.7cm , and might escape from the electrode, while an oxygen atom with a single charge certainly would, as its radius of curvature would be 6.7cm .

Assuming, then, that the negative current is carried by such positive ions from the gas film upon the source, it seems unnecessary to suppose that they are emitted with an appreciable velocity, as any of the electric fields used in the preceding experiments would be sufficient to take them through the magnetic field. It seems more probable that it is simply an ionization of the gas film by the α -rays. When the current in question is reduced to its minimum value by three or four days duration of the vacuum, the charge carried by it is from 5 to 10 per cent of that carried by all the α -rays from the polonium. (See § 6.) If the ions have lost a single electronic charge, this means that only one out of ten (or one out of five) of the α -particles, in its passage through the surface film, produces a positive ion which can get away. When the surface film is not so much reduced by long exposure to a high vacuum, this number may be considerably increased.

It is possible that negative ions of atomic size may also be produced, but the present apparatus is not adapted to decide this question for the following reasons. The magnetic field is by no means parallel to the electrode and some of the lines of force meet the surface of the electrode, though not at very large angles. A small proportion of the δ -electrons from any point of the electrode will leave in paths making only a small angle with the magnetic field and will hence escape. Now when a positive potential is applied to the gauze, the current of electrons leaving the source without a magnetic field is more than 500 times the ionic current under consideration. If a fraction of one per cent of these escape along the lines of force, it will be sufficient to cover up the possible small current due to negative ions. That this is the case will be seen in the following section.

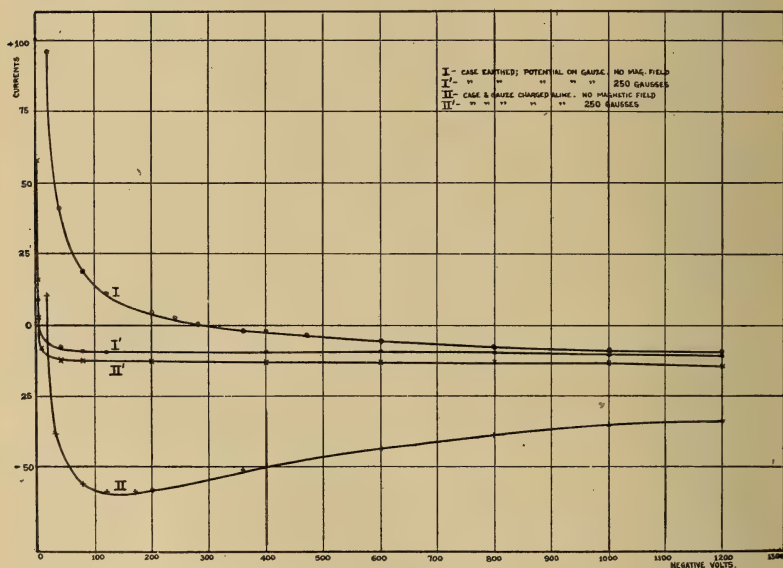
Effects have been observed by other investigators which, I believe, indicate the presence of ions from gaseous surface films. Thus in the recent, very careful determination by Danysz and Duane* of the charge carried by α -rays, the screen which limits the beam of α -rays and the opening of the Faraday cylinder which receives them are both covered with thin aluminium foil, the two foils being parallel and 0.8cm apart. A magnetic field of 8000 units parallel to these foils is used to curl up the β - and δ -rays. Even with this field, the authors found† that a difference of potential of only 2 volts between

* This Journal, xxxv, 295, 1913.

† L. c., p. 302.

the foils increased the charge received by the Faraday cylinder by 2.5 per cent or diminished it by 0.8 per cent according to the direction of the electric field; a potential difference of 1800 volts, they find, may affect the current as much as 8 per cent. It is very difficult to believe that these results can be due to a "drift" of the δ -electrons as the authors suppose; in their magnetic field, the radius of curvature of the path of an electron, moving with a velocity corresponding to 2 volts,

FIG. 4.



would be about 0.0005cm ; with a velocity corresponding to 1800 volts about 0.02cm . In neither case does it seem possible that an electron would be able to traverse the 0.8cm between the two foils. In fact, with 2 volts, it appears that it would require a very heavy ion to get through the magnetic field; with 1800 volts, an oxygen ion should get through.

§ 5.

An estimate of the reliability of the present measurements of the distribution in velocity of the swifter δ -rays will be facilitated by a consideration of fig. 4, which will also serve to give a clearer idea of the somewhat complicated phenomena which appear when α -rays fall upon a metal in a high vacuum. The figure shows graphically the results of measurements, all

of which were made on the same day, after the vacuum had been maintained for eight days. Curve I shows the currents received by the electrode, with the case grounded and with negative potentials between 20 and 1200 volts on the gauze cage. Curve II represents the currents when both case and gauze are charged alike. Curves I' and II' give the currents observed under similar electrical conditions as in I and II respectively, but with a magnetic field sufficient to give its maximum effect. Curve I is similar to those plotted in fig. 3 except for the change in scale due to the altered capacity, and for the fact that it begins at 20 volts instead of 40. According to the views advanced in § 4, an ordinate of this curve represents (with more or less accuracy) the number of electrons whose energies are greater than that represented by the abscissa; these ordinates, however, are to be measured, not from the axis, but from a line below it representing the constant negative current received by the electrode. This corrected zero line may coincide with I', or it may fall below it, since it is not certain that all the carriers of this current get through the magnetic field. Curve II represents the resultant of the current of δ -electrons from the source, and the current of tertiary electrons from the case: at 20 volts the δ -ray current predominates, but at higher potentials the tertiary electrons are in the majority. Their number decreases, however, as higher negative potentials are applied, owing to the decreased number of δ -electrons which reach the case. Their presence can still be detected, however, at 2000 volts. The course of II shows that the gauze cage acts as an entanglement to the tertiary electrons even when there is no field between it and the case; for when the cage is absent the tertiary current reaches a maximum at 40 volts, while with the cage (as shown in II), the maximum occurs at 150 volts.

On the view advanced in the preceding section, the negative ordinates of I' and II' represent the current carried by positive ions generated by the α -rays in the gas film upon the electrode. I have been unable to find an explanation for the difference between the two curves.

Considered as representing the distribution in velocity of the swifter δ -rays, the measurements represented by Curve I (or by the curves of fig. 3), are subject to certain sources of error, of which the following appear to be most important.

1. Some of the δ -electrons, whose velocity is nearly but not quite great enough to get through the electric field, may approach near enough to the gauze to be captured by the auxiliary field between it and the case. A consideration of the electric field in the neighborhood of the gauze shows, however, that to be so captured, an electron must approach fairly

near to the gauze; thus at any given voltage, the electrons improperly captured must lie between narrow limits of velocity and would form a small fraction of the total not returned to the electrode. Moreover, since the shape of the lines of force near the gauze remains the same, this fraction would not vary much for different potentials. The principal effect, therefore, of this error would be to increase each ordinate of the curve in nearly the same proportion, which would not seriously affect its accuracy.

2. Some of the tertiary electrons, set free by the δ -rays which strike the gauze, may be returned to the electrode. In a preceding section reasons have been given for supposing that these will form a nearly constant fraction of all the tertiary electrons from both gauze and case. If this is so, Curve I lies below its true position, each ordinate having subtracted from it a fraction of the corresponding ordinate of II. This would alter the course of I, depressing it most between 100 and 200 volts, and less at higher potentials. This correction, however, cannot be large. The wires of the gauze occupy only 17 per cent of its total area, and certainly most of the tertiary electrons which originate upon it must be captured by the auxiliary field. It is quite improbable that this correction can amount to more than 1 or 2 per cent of the ordinates of Curve II.

3. Some of the δ -rays originating upon the sides of the box-source will cross its opening obliquely, and will be *deflected*, so as to strike the box, by fields too small to stop them. Thus at any given potential, some electrons which should get away will not do so, and the ordinates of Curve I will be thereby diminished. But the number thus improperly stopped at any voltage must be a nearly, or quite, constant fraction of those which should escape, so that the effect would be merely to change the scale of the curve.

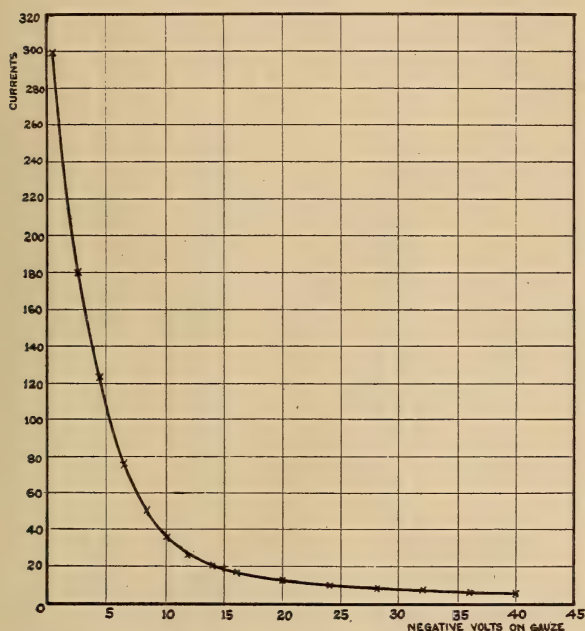
We may reasonably conclude, I think, that the measurements given represent a fair first approximation to the distribution in velocity of the swifter δ -rays. It will probably be possible to improve the accuracy of the determination by using a more intense source of α -rays and receiving a restricted beam of δ -rays in a Faraday cylinder. A suitable source of α -rays for this method is not at present at my disposal.

§ 6.

The preceding measurements have had to do only with δ -rays whose velocities exceeded 20 volts. By reducing the sensitiveness of the electroscope to somewhat less than one-eighth of its former value, measurements could be taken with smaller negative potentials on the gauze cage. A series of

observations made in this manner is represented in fig. 5. It is within this region that all previous measurements of the velocities of δ -rays have been, so far as I know, confined. Most, if not all, of such measurements have been, I believe, to a considerable extent vitiated by two circumstances: lack of knowledge of the existence of the swifter rays and of the tertiary rays which they produce; and the fact that the α -rays were allowed to pass through the field, thus giving two sources

FIG. 5.



of δ -rays, and of tertiary rays, with much consequent confusion of the results.

Among neither the swifter, nor the slower, rays is there any approach to the Maxwellian exponential distribution; if it were so, the integrated curves (those of figs. 3, 4, and 5) would also be exponential. This is not true in either case;* the diminution in the ordinates is too rapid at the lower potentials and too slow at the higher. If we plot \sqrt{V} instead of V , thus making the abscissæ proportional to velocities

* In the curves of figs. 3 and 4, allowance must be made for the depression of the zero line; but no reasonable adjustment of this sort will bring the curves near to an exponential form.

instead of to kinetic energies, the result is still very far from an exponential curve

The form of the curves, however, for both the swifter and the slower electrons suggests an equation of the form $yx^n = C$. In fact, a very fair agreement between the observations from 30 to 500 volts, and this equation may be obtained by using $n = 0.75$, as may be seen from Table II. In this table the observed currents have been increased by 12 units to allow for the ionic current discussed above.

TABLE II.
 $yx^n = C$ $n = 0.75$

x (volts)	y (obs + 12)	y (calc.)	Diff.
20	108.	89.	19.
40	53.	53.	0.
80	31.	31.2	— 0.2
120	23.5	23.2	+ 0.3
160	19.	18.7	+ 0.3
200	16.7	15.8	+ 0.9
240	14.6	13.8	+ 0.8
280	11.8	12.3	— 0.5
320	11.4	11.1	+ 0.3
360	10.5	10.2	+ 0.3
400	9.5	9.4	+ 0.1
480	8.5	8.2	+ 0.3
600	6.2	6.9	— 0.7
800	4.	5.6	— 1.6
1000	2.6	4.7	— 2.1
1200	1.3	4.1	— 2.8

The departure of the observations from the equation at the higher voltages may or may not be of significance, since the currents under these conditions were small and could not be very accurately measured, and the placing of the zero line is uncertain. At the lower potentials, however (beginning at 20 volts), the equation does not fit at all. This may well be due to the large admixture of tertiary electrons at these potentials, while above 40 volts there can be few, if any, of these. An approximate representation of the distribution of the slower electrons may be obtained with an equation of the same form, but with a larger value of n , between 1.5 and 2.

In order to get an idea of the relative magnitudes of the currents observed under various conditions, a rough series of comparisons was made by altering the sensitiveness of the electroscope, and introducing a small mica condenser. The results were as follows:

Electronic current at — 40 volts.....	43.
“ “ “ — 20 “	100.
“ “ “ — 2 “	1700.
“ “ “ 0 “	2700.
“ “ “ + 40 “	5800.
Current carried by α -rays.....	200.
Minimum ionic current.....	10.

It will be seen that the swifter electrons with which we have been principally concerned form only a small part of the total number which leave a metal when it is struck by α -rays. But the fact that α -rays can cause electrons to be projected with such speeds is undoubtedly a fact of considerable importance, whether these electrons be few or many; it must have some bearing upon the theory of ionization by α -particles and of their passage through matter. It is not altogether surprising that α -particles should cause electrons to be projected with velocities corresponding to some hundreds of volts. According to the theory of Einstein, the energy of electrons projected under the influence of ultra-violet light is a linear function of the frequency of the light. This theory has been extended with some degree of success to the electronic emission caused by Röntgen rays, taking, instead of the frequency, the time occupied by the pulse in passing over an electron, and estimating this as well as can be done in the present state of knowledge. If we assume that the effective field about an α -particle has the diameter of an atom, 10^{-8}cm , then, since its velocity is about $2 \times 10^9 \frac{\text{cm}}{\text{sec}}$, its time of passage over an electron will be $\frac{1}{2} \times 10^{-17}$ seconds. The frequency of ultra-violet light is about $\frac{2}{3} \times 10^{16}$ seconds, so that we might expect the maximum energy of the δ -rays to be of the order of 100 times that of photoelectric electrons.

It has been shown that the number of slow δ -electrons varies with the speed of the α -rays in much the same manner as the number of ions produced in a gas. I have not yet been able to determine whether this is so with the swifter δ -rays, nor how their distribution in velocity varies (if at all) with the speed of the α -rays. Knowledge of this sort might throw considerable light upon the relations between the electrons of various speeds, and upon the mechanism of ionization by α -rays, about which very little is known at present.

Summary.

1. When α -rays fall upon a metal, electrons are emitted with velocities varying continuously from a very small value to more than $2.7 \times 10^9 \frac{\text{cm}}{\text{sec}}$, which corresponds to a potential differ-

ence of 2000 volts. It is proposed to include under the name " δ -rays," all the electrons which owe their origin to the direct action of the α -rays,—the swifter ones as well as the slower ones previously known.

2. Evidence is given for the view that, in addition to the δ -rays, positive ions are also produced when α -rays impinge upon a metal in a very high vacuum; these ions appear to come from the layer of adsorbed gas upon the metal. By maintaining the vacuum for several days, the current carried by these ions may be reduced to a small value,—from 5 to 10 per cent of that carried by the α -rays themselves. The present experiments do not determine whether or not these ions leave the plate with an appreciable velocity in the absence of an electric field; but there is some evidence that the velocity is, at all events, small.

3. When the swifter δ -rays fall upon a solid it emits electrons of slow speed which, in the present paper, are referred to as tertiary electrons. Their number is considerably greater than the δ -rays which produce them. The existence of the tertiary electrons makes it difficult to determine with accuracy the distribution in velocity of the δ -rays. A large number of tertiary electrons come from the source of δ -rays itself, and their presence in the beam of δ -rays makes it impossible to draw valid conclusions as to the number of true δ -electrons of slow speed (less than 10 or 20 volts).

4. The distribution in velocity of the δ -rays between 20 and 1200 volts has been determined, and reasons are given for believing that the measurements represent a fair approximation to the true distribution. The number of electrons having a given kinetic energy is not an exponential function of either the energy or the velocity. Between 30 and 500 volts, the results are approximately represented by an equation of the form $yx^n = c$ where y is the number of electrons whose kinetic energy is equal to or greater than x , and $n = 0.75$. It is impossible to say whether or not the departure of the measurements from this equation at potentials higher than 500 volts is significant; the quantities measured are small and their values are rendered somewhat uncertain by the presence of the positive ions and of the tertiary electrons. On the other hand, the fact that the slower electrons (under 20 volts) do not follow the same law of distribution in velocity as the swifter ones is to be expected; the presence of tertiary electrons from the source, in the beam of δ -rays, should greatly increase the numbers of the very slow electrons, as is, in fact, found to be the case.

Sloane Laboratory, Yale University,
April 15, 1913.

ART. XII.—*The Banded Gneisses of the Laurentian Highlands of Canada*; by MORLEY E. WILSON.

Introduction.

THE larger part of the Pre-Cambrian oldland of northeastern Canada is composed of a complex of banded gneisses, which, in accordance with the designation of Sir William Logan, is generally called Laurentian. It is now generally believed that these gneisses, for the most part, originally constituted huge batholithic masses of magma and that the foliated structures which they possess originated as a result of deformation. But the investigation of the origin and structures of the gneissic complex has not been carried beyond these generalizations.

During the summer of 1912, in making a geological reconnaissance across the Laurentian highlands of Quebec, an opportunity was afforded the writer to study the Laurentian banded gneisses in some detail, and to collect additional data bearing on their mode of origin and their relationship to the structural history of the Laurentian plateau. In the following pages is embodied a brief account of this investigation.

Geological Relationships of the Banded Gneisses.

The Pre-Cambrian rocks occurring in northeastern Ontario and western Quebec may be divided stratigraphically into two strikingly different divisions: an older complex and a younger group of slightly disturbed Huronian sediments which occur as erosion remnants scattered here and there over the surface of the basement upon which they were deposited. Since the banded gneisses are confined entirely to the basement complex, it is their relationship to the other rocks of that division of the Pre-Cambrian that is of special interest in this connection.

Near the southern border of the Laurentian plateau the banded gneisses have their greatest development in a wide belt which extends continuously from Georgian bay to the Gulf of St. Lawrence. To the south of this belt, the gneisses intrude and include bands and masses of crystalline limestone and other sediments, the masses and bands gradually decreasing in size and number towards the north until finally replaced entirely by the banded gneisses. To the north of the gneissic belt, in the vicinity of Lake Timiskaming and extending westward to the north shore of Lake Huron and eastward to Lake Mississinewa, a belt of volcanic flows and sediments occur in the basement complex which like the sediments of the southern belt are intruded by granite and gneiss and like the sediments of the

southern belt gradually disappear when traced (southward) in the direction of the central belt of gneisses. Throughout western Quebec and northeastern Ontario, therefore, there is everywhere a basal Pre-Cambrian complex, the surface rocks of which (sediments and volcanic flows) may be divided lithologically into two provinces, a southern limestone belt known as the Grenville series, and a northern belt of volcanic flows and sediments to which the writer has given the name Abitibi group. Between the Grenville series and the Abitibi group intervenes the central belt of Laurentian banded gneisses.

Geological investigation throughout the world has shown that wherever mountains have been greatly denuded, batholithic masses of rock are generally found at their centers, and since the Laurentian banded gneisses occur in a central belt intervening between belts of folded surface rocks, it is inferred that the Laurentian gneissic complex in this locality originally formed the core of a Pre-Cambrian mountain chain and constitutes a geanticlinal axial belt intervening between geosynclines formed by the rocks of the Abitibi group and the Grenville series. But denudation was carried to so profound a depth in Pre-Cambrian time that not only were all the roof rocks stripped from the central geanticlinal mass but the geosynclines were truncated so close to their bottoms that they also are intruded by batholiths of granite and gneiss. Adams and Barlow have concluded from their areal work in eastern Ontario, that these smaller batholiths are anticlinal in their relationship to the Grenville series.* Whether this relationship also holds in the case of the batholiths intruding the Abitibi group is as yet unknown.

It is of historical interest in this connection to note that Logan, in his report on the geology of the Ottawa river,† regarded the metamorphic series, which he afterwards named Laurentian, as forming the axis of an anticlinal arch lying between northern and southern troughs of Huronian and Paleozoic sediments; a conception analogous to that suggested in the foregoing paragraph. The two conceptions differ, however, in that Logan assumed the anticlinal relationship to exist between the basement complex (Laurentian), and the Huronian and Paleozoic rocks, whereas in the present paper the anticlinal relationship is regarded as existing, not between the basement complex and younger series, but within the basement complex itself.

Definition of Laurentian.

The name Laurentian was first used by Sir William Logan to designate the great complex of gneisses and associated rocks

* Memoir No. 6. G. S. Dept. of Mines, Can., p. 16, 1910.

† Ann. Rep. G. S. C., p. 40, 1845.

which occur so extensively throughout the northern part of the St. Lawrence basin. As a result of the investigations carried on by Logan and his associates during the early years of the Canadian Geological Survey, it was concluded that the Pre-Cambrian rocks of eastern Canada fell naturally into two main stratigraphical divisions; an older complex, the Laurentian, and a younger series, the Huronian. Logan further attempted to subdivide the basement complex into an Upper Laurentian, consisting of anorthosite and anorthosite gneiss, and a Lower Laurentian composed of two groups, the younger of which consisted largely of limestone, and the lower of gneiss. Logan's conception of the Pre-Cambrian succession may thus be tabulated as follows:

Azoic (Pre-Cambrian)	{	Huronian		
		Laurentian	{	Upper Laurentian, Labrador, anorthosite or Norian series.
				Lower Laurentian {
				Grenville series.
				Ottawa gneiss.

Although Logan included the rocks of the Abitibi group in his Huronian instead of placing them in the Laurentian where they actually belonged, and thus went astray in applying his Pre-Cambrian classification, yet the work of later years has shown that, theoretically, his classification of the Pre-Cambrian into Laurentian and Huronian was wholly in accord with the facts. Unfortunately, the importance of the great stratigraphic break which separates the Huronian from the basal complex and the consequent necessity for a group name to include all the rocks of the older complex was not generally recognized, and in subsequent years it became customary to limit the term Laurentian to merely the granite and gneiss.* It is with approximately the latter significance that the name is here used by the writer to include all the acid plutonic rocks of the basement complex regardless of possible difference in age. Defined in terms of geological relationships, the Laurentian includes the granite and gneiss which intrude the Grenville series and the volcanic complex (Abitibi group) of the Lake Mistassini-Lake Timiskaming-Lake Huron region. It would also include any granite or gneiss which might lie unconformably beneath either the Grenville series

* Report of the Special International Committee on the Correlation of the Pre-Cambrian Rocks of the Adirondack Mountains and the "Original Laurentian Area" of Eastern Ontario, Jour. of Geology, vol. xv, pp. 191-217, 1907.

or the Abitibi group. The upper limits of the Laurentian are defined by the erosion surface that separates the basement complex from the Huronian, or defined more locally, the plane which separates the Cobalt series from the older complex, in the Timiskaming region, and the original Huronian rocks from the basement complex, on the north shore of Lake Huron. It is probable, according to this definition, that the anorthosites (Logan's Upper Laurentian) should be classed as Laurentian for these rocks are in part transformed into gneiss and probably belong essentially to the basement complex.*

Lithological Character.

The rocks of the Laurentian complex may be classified (1) according as to whether they are massive or foliated, and (2) according to their mineralogical composition. To the massive rock types belong nearly all of the small batholithic masses which intrude the northern volcanic complex (Abitibi group) and, to a much more limited extent, some of the batholiths which intrude the southern limestone† complex (Grenville series). The foliated rocks, on the other hand, include nearly the whole of the central gneissic belt which separates the Abitibi group from the Grenville series. Classified according to mineralogical composition, the rocks of the Laurentian complex include the following types: granite, syenite, granodiorite, diorite, pegmatite, aplite, pyroxenite, amphibolite, and garnetiferous mica schist.

Granite and Granite-gneiss.—The granite and granite-gneiss of the Laurentian complex are granular, fine- to coarse-grained rocks consisting essentially of quartz and alkalic feldspar (orthoclase, microcline, albite, and oligoclase), with biotite or hornblende or biotite and hornblende together as ferromagnesian constituents. The biotite granite and granite gneiss is, however, much more common than the hornblende variety. The common accessory minerals present are titanite, epidote, muscovite, garnet, apatite, zircon, and magnetite, but allanite, tourmaline, rutile, graphite, cyanite, arfvedsonite, and ægirine have also been found in some thin sections of the granite gneiss.‡ From the microscopic examination of the granite and granite gneiss it is seen that, in some places, the constituent minerals are remarkably fresh while, in others, the feldspars are largely replaced by sericite, and the hornblende and biotite by chlorite. Between these two extremes an intermediate rock

* Adams, F. D.: "Über das Norian oder Ober-Laurentian von Canada"; *Neues Jahrbuch für Mineralogie*, etc., pp. 419-498, 1892.

† According to Adams and Barlow, *Memoir No. 6*, G. S. Branch, Dept. of Mines, Can., 1910.

‡ Barlow, A. E., *Ann. Rep. G. S. C.*, p. 871, 1897. Wilson, M. E., *Sum. Rep.*, G. S. Dept. of Mines, Can., 1913.

type is also common in which sericitized feldspar occurs enclosed in a matrix of fresh, granular quartz and microcline. In some thin sections the minerals show by their undulatory extinction and granulated character that they have been subjected to intense mechanical deformation. In others, however, all these evidences of deformation are entirely wanting.

Syenite and Syenite-gneiss.—The syenite and syenite gneiss are commonly a grey to rusty red rock which, in most localities, shows a remarkable tendency to disaggregate into its constituent mineral grains on the weathered surface. They consist essentially of orthoclase, albite, microperthite, ægirine, and dark brown biotite. The accessory constituents observed are titanite, apatite, zircon, epidote, and magnetite. Under the microscope it can be seen that the disaggregation on the weathered surface arises from irregular fractures which traverse the rock along the contacts of the mineral grains. The cause of the fractures is not apparent, but they are most probably related in their origin to the expansive pressure which no doubt accompanied the slight decomposition which has occurred in the ægirine.

Granodiorite and granodiorite-gneiss.—The granodiorite and granodiorite-gneiss are rocks of similar appearance to the granite and granite-gneiss, but their mineralogical composition shows them to occupy an intermediate position between diorite and granite. They contain much less quartz and orthoclase than the granite and correspondingly more plagioclase, and biotite is replaced by hornblende as the dominant ferromagnesian constituent. The accessory mineral constituents, mineral alterations and evidence of mineral deformation are the same in the granodiorite as in the granite and granite gneiss.

Diorite and diorite-gneiss.—The diorite and diorite-gneiss are dark rocks containing an abundance of glistening crystals of hornblende. Examination under the microscope shows most of the rocks of this class to consist essentially of blue-green hornblende and plagioclase, either albite, oligoclase or andesine, but in some thin sections the proportion of plagioclase becomes so small that the rock might be more appropriately called a hornblendite. The common accessory minerals observed are garnet, magnetite, biotite, titanite, epidote, and zircon. The hornblende and biotite are generally more or less altered to chlorite, and the plagioclase in some thin sections is entirely replaced by sericite and epidote.

Pegmatite and aplite.—These rocks are among the most common in the Laurentian gneissic complex occurring, in part, as thin lenses in the banded gneiss and, in part, as dikes transverse to the foliation and banding. They consist largely of quartz and alkalic feldspar (orthoclase, microcline and albite),

but muscovite, biotite, garnet, epidote, and titanite are also commonly present. Other minerals less commonly present are cyanite, molybdenite, graphite, and allanite. Like the other rocks of the complex, the pegmatite and aplite have undergone some mineralogical and mechanical alteration, the evidences of deformation being particularly apparent.

Pyroxenite, amphibolite, and amphibolite-gneiss.—The rocks in this subdivision of the Laurentian have been grouped together because they are largely composed of lime silicates, and hence are similar in chemical composition, although mineralogically somewhat different. They occur chiefly as small lenticular masses in the banded gneiss, and are largely limited to a few localities near the south side of the central belt of gneisses. The pyroxenite consists chiefly of diopside, while the amphibolite is largely composed of either hornblende or tremolite. Other minerals observed in these rocks were biotite, scapolite, garnet, a carbonate, and serpentine, the latter occurring as an alteration product from the diopside.

Garnetiferous mica-schist.—Within the central belt of banded gneisses, particularly near their northern border, there are areas of fine-grained garnetiferous mica schist very similar in appearance to some of the mica schist of sedimentary origin occurring in the Abitibi group farther to the northward. This mica-schist consists of biotite quartz, orthoclase, albite, and either pink or red garnet and possesses a mosaic-like texture very similar to the crystalloblastic texture of the paragneisses.

Structural Features.

Foliation.—By far the larger part of the rocks comprising the Laurentian complex are foliated and for this reason are largely classed as gneisses. This foliation has been brought about, for the most part, by the parallel orientation of biotite plates and hornblende prisms but also, in some cases, by the flattening of the feldspar and quartz in the same plane. Very commonly the biotite of the biotite gneiss is seen to “eye” around small lense-shaped fragments of feldspar, giving rise to the characteristic augen structure, which results from deformation. The trend of the foliation, like that of the banding, indicates that it has the form of anticlines and synclines simulating the structure of folded sedimentary rocks in every respect.

Banding.—The most striking and the most characteristic structural feature of the central belt of Laurentian gneisses is the banding which is everywhere developed. The extreme complexity of the structures exhibited by these bands and the heterogeneity of the rocks which they contain even in a single

rock outcrop are scarcely capable of description, yet when examined over broad areas this complexity and heterogeneity is so uniform that it becomes monotonous. The banding of the gneisses may arise either from (1) a variation in the proportion of minerals present in the same rock or (2) by the alteration of bands of different rock. Thus, one of the most common types of banding is brought about by the alternation of bands of biotite gneiss, containing varying proportions of biotite so that a light band, in which little biotite is present, alternates with a dark band containing a large proportion of biotite. In a similar manner, variations in the proportion of hornblende in the hornblende granite gneiss, the granodiorite-gneiss or the diorite-gneiss result in a banded structure. The second type of banded structure, in which the alternate bands are composed of different rocks, may also be combined with bands of the first types, and in this way an almost infinite variation in the composition of the bands may occur. The commonest rock of the banded gneiss is the biotite, or biotite hornblende granite gneiss; but pegmatite and aplite are also important, composing not less than 15 per cent of the whole. The proportion of other rocks is small, so that the central belt of Laurentian gneisses, considered as a whole, is granitic rather than dioritic in composition. The width of the bands may vary from a fraction of an inch to hundreds of feet. When followed along the strike they are found to pinch out as though they were, in reality thin lenses. This lenticular character is particularly evident in the case of the pegmatite, which commonly occurs in a succession of lenses around which the foliation in the surrounding gneiss bends in a manner very similar to that which occurs on a small scale around the augen of feldspar in the augen gneiss.

Granulation.—That granulation has occurred to a large extent in the banded gneisses is apparent from the abundance of augen gneisses and from the evidences of strain and fragmentation seen in some thin sections. Recrystallization has followed granulation in many cases, however, for in many rocks which have very evidently suffered granulation, the granular quartz and feldspar which surrounded the lense of the augen contain a large proportion of microcline and are much fresher in appearance than the central core.

Folding and Faulting.—The study of the structure of the banded gneisses indicates that they have been folded in a manner very similar to that exhibited by deformed sedimentary rocks. While the bands are not continuous over wide areas like sedimentary beds, yet, all the various types of folds are present on a small scale and, in places, anticlines and synclines nearly a half-mile in cross section, can be recognized. These

folds are generally pitching and since the strike of the bands is dominantly in a northeasterly-southwesterly direction, it is inferred that the banded gneiss has been folded into pitching anticlines and synclines having a northeasterly-southwesterly trend. In some places the biotite has been smeared out along the contacts of the bands, giving a slickensided appearance which has evidently resulted from differential movements accompanying the folding.

In describing the structure of the Laurentian gneisses* occurring in eastern Ontario, Adams and Barlow note that the foliation of the gneiss near the border of the batholith corresponds to the strike of the surrounding sedimentary rocks and conclude that the batholiths are anticlinal in their relationship to the Grenville series, the anticlinal axes trending N. 30° E. They also point out that the trend of the foliation and banding in the batholiths is commonly oval or elliptical in form, and while no further statement is made by the authors as to structure of the gneiss, it seems apparent, from the trend of the foliation indicated on their maps, that the gneiss in that locality also has a folded structure similar to that of the central belt of gneisses of the Laurentian complex.

On the whole, faulting has been subordinate to folding in the Laurentian banded gneisses, but faults of both the overthrust and normal types are present. The pegmatite and aplite dikes which are transverse to the banding of the gneiss have been very commonly intruded along fault planes, for the bands on opposite sides of many of the dikes have been relatively displaced.

Origin.

A discussion of the possible modes of origin of the Laurentian gneissic complex resolves itself into two problems: (1) Are the banded gneisses sedimentary or igneous in origin, and (2) in what manner did the rocks become banded, folded and foliated into their present condition.

Sedimentary or Igneous Origin.—The early Canadian geologists, in common with geologists working in other parts of the world, generally assumed that banded gneisses owed their bedded-like structure to subaqueous deposition.† In the case of the Laurentian banded gneisses, this seemed particularly obvious, for they were bedded and folded like stratified sediments, and were intimately associated with limestone and other rocks which were undoubtedly sedimentary in their origin. But with the application of petrographical and chemical inves-

* Memoir No. 6, Geol. Surv., Dept. of Mines, Can., 1910.

† Geology of Canada, p. 29, 1863. Sterry Hunt, Royal Society of Canada, vol. ii, 1884.

tigation to the problem, the sedimentary hypothesis was gradually abandoned—as regards the major part of the Laurentian complex—in favor of the igneous hypothesis, which is now generally accepted.*

In describing the lithological character of the gneissic complex it was noted that within the axial belt particularly near its northern border, garnetiferous mica schists occur which are probably of sedimentary origin. Likewise, along the southern border of the central Laurentian gneissic complex, fine-grained rusty gneisses and amphibolites occur which are believed from their lithological character and chemical composition to be altered sediments, the former being a mashed quartzite or arkose and the latter a metamorphosed limestone.† Thus it is probable that the proportion of sediments associated with the Laurentian is somewhat larger than is generally supposed, yet the characteristics of the major part of the complex is such as to point conclusively to an igneous origin. The evidence upon which this conclusion is based may be summarized briefly as follows:—

(1) The complex is largely composed of granite, diorite, granodiorite and pegmatite, and hence is composed of rocks having the mineralogical and chemical composition‡ and texture which belong to rocks of igneous origin.

(2) Pegmatite constitutes a large and essential portion of the Laurentian complex and occurs not only in parallel bands but as dikes transverse to the banding.

(3) The bands in the gneiss pinch out when followed along the strike, whereas sedimentary beds composing uniformly stratified series are generally continuous for long distances.

(4) The extreme local heterogeneity of the Laurentian complex and the uniformity of this heterogeneity over many thousand square miles is not characteristic of sedimentary rocks.

(5) The dominant sediments which result from the decomposition of igneous rocks are argillaceous, and since the Laurentian banded gneisses have an areal extent in Canada of not less than 2 million square miles, it might be expected that a considerable proportion of the complex would consist of slates, but on the contrary it is almost entirely composed of rocks approaching the composition of arkose or quartzite.

It may therefore be assumed as unquestioned that the banded gneisses of the Laurentian plateau, in their most typical development, are of igneous origin.

* Adams, F. D., *Jour. of Geol.*, vol. i, pp. 325-340, 1893. Barlow, A. E., *Ann. Rep.*, C. G. S., p. 51, i, 1897.

† Adams, F. D., *this Journal*, vol. 1, pp. 58-69, 1894. Adams, F. D., *Ann. Rep.*, G. S. C., vol. viii, 1895. Adams and Barlow, *Memoir No. 6*, *Geol. Surv.*, Dept. of Mines, Can., 1910.

‡ Barlow, A. E., *Ann. Rep. G. S. C.*, p. 55, I, 1897.

Banding, folding and foliation.—If the banded gneisses of the Laurentian complex are igneous in origin, then it becomes necessary to frame an hypothesis which will account for the development of a banded, folded and foliated structure in rocks which originally constituted a batholithic magmatic mass. The various ways by which a banded structure might develop in an igneous rock are the following :—(1) by the flattening out of fragments of the invaded rock forming the batholithic roof ; (2) by *lit par lit* injection,—that is, by the intrusion of dikes parallel the foliation of a gneiss ; (3) by the deformation of (a) a heterogeneous complex of igneous rocks in the zone of flowage long after consolidation ; (b) a heterogeneous magma during or immediately after consolidation.

(1) The development of a banded structure along the contact of the Laurentian batholiths by the flattening out of xenoliths has been advocated by a number of Canadian geologists,* and is undoubtedly an important mode of origin for the structure in some places, but this method alone cannot account for the banded structure of the Laurentian axial complex because the composition of the bands is, for the most part, wholly different to that of the rocks constituting the batholithic roof.

(2) A banded structure may originate by *lit par lit* injection, wherever a magma intrudes a rock which, because of its bedded or foliated structure, possesses a prominent cleavage. Thus, where the Laurentian rocks intrude some of the sedimentary schists of the Abitibi group, the granite, aplite and pegmatite commonly occur, as sheets or dikes paralleling the foliation. There are also some sharply defined dikes of pegmatite and aplite in the gneissic complex which parallel the foliation of the gneiss and were probably intruded in this way, but it is scarcely possible that the banded structure of the Laurentian gneisses has originated to any great extent by *lit par lit* injection for if such were the case, the bands formed by intrusion (1) should be connected in places by dikes transverse to the foliation, (2) should be sharply defined on their contacts, and (3) should be continuous for considerable distances when followed along the strike. Instead of these features being present, the bands were never seen to connect transversely, the contacts of the bands are generally poorly defined; the mineral grains interlocking across the line of junction, and the bands commonly pinch out in short distances when followed in the direction of their trend.

(3) The third hypothesis to explain the origin of the banded gneisses has been divided into two subdivisions according to

* Lawson, A. C., Ann. Rep. G. S. C., vol. iii. Part I, p. 138F, 1887. Adams, F. D., and Barlow, A. E., Memoir No. 6, Geol. Surv. Dept. of Mines, Can., 1910. Miller, W. G., and Knight C., Ann. Rep., Bur. of Mines, Ont., vol. xx, pp. 280-284, 1911.

the time at which the deformation occurred, that is, according to whether it took place at the time of intrusion or long after consolidation.

Wherever the Laurentian gneiss and granite have been observed in contact with rocks of the Abitibi group and the Grenville series, they are always intrusive into the latter, yet the presence of conglomerate containing granite pebbles in the Abitibi group and the occurrence of siliceous sediments in the Grenville series indicate that older granitic rocks were at one time widely present in the region and it might be possible that this ancient granite comprises a considerable part of the Laurentian gneissic complex. However, no evidence was observed anywhere throughout the gneissic complex of the presence of granite or gneiss of two distinct periods of intrusion, and if such occurred, the evidence of their presence has been entirely obliterated by deformation. On the other hand,—if it be assumed that the banding of the banded gneisses originated as a result of deformation,—it is apparent that the larger part of the simplex was undergoing consolidation at the time the banding was being developed; for pegmatite and aplite were being given off from the magma during stages in the development of the bands, as shown by the occurrence of dikes of these rocks transverse to the banding and in all stages of deformation, some being exceedingly crumpled and others undisturbed.

In a paper published in 1887 "On the Origin of Certain Banded Gneisses," J. J. Teall* concluded that banded gneisses might originate by the deformation of a heterogeneous plutonic mass, the evidence for this conclusion being (1) that plutonic rocks are commonly heterogeneous and (2) that a plutonic igneous mass may undergo deformation during intrusion or later as a result of mountain-building stresses. It is proposed in this paper to suggest that the Laurentian banded gneisses, in the particular locality studied by the writer, not only originated by the deformation of a heterogeneous plutonic mass but that the heterogeneity was itself developed, to a large extent, as a result of the deformation and that the deformation was related to mountain-building stresses which acted upon the magma during and following its consolidation.

Plutonic masses of rock when examined over areas of considerable extent, are generally found to be heterogeneous. This heterogeneity must obviously be due to either assimilation of foreign rock, or to differentiation within the magma itself. That assimilation occurred in the case of the Laurentian complex is evident from the occurrence of partially assimilated fragments of both the Abitibi group and the Grenville series along the batholithic border, but whether this process was of

* *Geol. Mag.*, vol. iv, pp. 484-492, 1887.

great importance or not, is unknown. It is also probable that basic and acidic aggregations and other variations were present in the Laurentian as in other plutonic masses, but it is doubtful whether all of these differences, as developed in normal plutonic rocks, would account for the excessive heterogeneity which would have to be present to result in such variability in composition as occurs in the Laurentian complex.

Throughout the northern geosynclinal belt formed by the rocks of the Abitibi group, small batholiths of granite occur which are presumably offsets from the main Laurentian magmatic mass. These, because of their small size, would no doubt consolidate much more quickly than the larger central complex, so that, in them, we should expect to find the record of the early stages in the series of events which resulted in the development of the Laurentian banded gneisses. On making an examination of these northern batholiths, it is found that although they consist largely of granite instead of gneiss they also are exceedingly heterogeneous and the heterogeneous portions are similar in composition to the most common bands of the banded gneisses. Thus, in some places in the small batholiths, a granite containing very little biotite may be seen to cut across another granite in which this mineral is more abundant, or a biotite granite may cut a hornblende granite in a similar manner. Long schlieren of granite very rich in biotite are also common. These variations are generally poorly defined and are gradational from basic to acidic in composition from which it is inferred that they are differentiated parts of the same magmatic mass. This differentiation was evidently assisted by deformation which, in some cases, caused movements in the viscous magma, thus dragging it out into long schlieren and, in other cases, broke up the magma after it had become solid so that the central magma of more acid composition flowed in to fill up the fractures. By this process of deformation during consolidation, a magmatic mass originally homogeneous might continue to become more and more heterogeneous as the kneading process continued, material of progressively more salic composition being squeezed out through fractures from the interior.* Not only would heterogeneity be developed by this process, but the variations in the magma would, as consolidation continued, be flattened out into thin lenses which, because of their different competency, would behave like sedimentary beds and assume a folded structure.

In discussing the geological relationships of the banded gneisses it was pointed out that they apparently formed the truncated base of a Pre-Cambrian mountain chain, and since mountain building is generally accompanied by deformation it

* Harker, A., *The Natural History of Igneous Rocks*, 1909.

follows that if the mountain deformation continued until the axial complex began to consolidate, it would also be deformed. The action of the mountain-building stresses on the magmatic central mountain mass thus affords a complete explanation of the cause which brought about not only the folding, foliation and granulation in the banded gneisses but also explains how the differentiation of the magma was brought about so that a banded structure was made possible. During the final stages of deformation, the gneissic complex had evidently passed, for the most part, from the zone of flowage to the zone of fracture; for slickensiding between the bands, granulation and fracture became the dominant deformational processes.

Summary.

In the foregoing pages, the geological relations, lithological character, and structural features of the banded gneisses of the Laurentian highland of Canada have been briefly described, and from these data it has been concluded that the gneisses complex was originally the magmatic center of a Pre-Cambrian mountain chain and that mountain-building stresses acted upon this axial magmatic mass during its consolidation with the result that it (1) underwent differentiation aided by deformation during consolidation and (2) by further deformation, the differentiated portions became flattened out into bands which were then crumpled into their present folded structure. This hypothesis is supported not only by observations in the field where the various stages in the process may be seen, but also by the fact that it affords a complete explanation of the heterogeneity, banding, foliation, folding and other characteristic features of the gneissic complex. Moreover, it postulates only such conditions as are generally accepted by geologists the world over, and assumes only such effects as must necessarily result wherever such conditions arise in the earth's crust.

Stated more fully, the conclusions with regard to the relations, character, and origin of the banded gneisses occurring in the southern part of the great Pre-Cambrian Canadian oldland are as follows:

(1) The Pre-Cambrian basement complex occurring throughout northeastern Ontario and western Quebec may be divided into three divisions, a northern geosynclinal belt consisting of highly folded sediments and volcanic flows (Abitibi group), a southern geosynclinal belt chiefly composed of crystalline limestone (Grenville series), and an intermediate geanticlinal zone of Laurentian banded gneisses.

(2) The banded gneisses are largely igneous in origin.

(3) From the geographical and structural relationship of the gneissic complex to the rocks of the Abitibi group and Gren-

ville series, it is inferred that the banded gneisses originally constituted the magmatic centre of a Pre-Cambrian mountain chain.

(4) As regards the origin of the folded, banded and foliated structure of the gneisses, it is concluded that these are all genetically related in the Laurentian mountain-building deformation which acted upon the magmatic axial mass during its consolidation. While it is recognized that heterogeneity in a magma may be caused by the stopping off and partial assimilation of fragments of the batholithic roof, it is concluded from the field evidence that the principal factor in bringing about the heterogeneity of the Laurentian complex was differentiation aided by deformation during consolidation. By this process, the magmatic mass was constantly being broken up, and the residual fluid magma of slightly different composition squeezed out to fill the fractures around the broken fragments. The variations in the complex produced in this way were then flattened out and crumpled into a folded structure resembling that assumed by deformed sedimentary beds. Thus by the action of mountain-building stresses on a magmatic axial mass a folded and banded gneissic complex such as that occurring in the Laurentian plateau may be developed.

ART. XIII.—*Deep Wells at Findlay, Ohio*; by D. DALE
CONDIT.*

FINDLAY lies in the midst of the "Trenton" oil and gas field of northwestern Ohio and has been in the foreground as a producer for over thirty years. Until recently all of the production has come from near the top of the so-called "Trenton" limestone, but at Tiffin and other localities considerable oil is now being found at a horizon 600 or more feet lower stratigraphically. During the summer of 1912 the citizens of Findlay formed a company with the object of testing the deeper strata and determining the "thickness of the Trenton." Drilling was commenced on the D. L. Norris farm in section 3, Marion Township, about three miles northeast of the city. A test well was also started by the Ohio Oil Company on the J. H. Grubb farm in section 9, Liberty Township.

In November, when the Norris well had been drilled to a depth of nearly 3000 feet, Mr. J. E. Fennerty of Findlay informed the United States Geological Survey by telegram: "Well now about 200 feet below Trenton, and drillings indicate granite formation, very hard and drill slow." Dr. Johnston, who through the courtesy of the Carnegie Geophysical Laboratory has been coöperating with the U. S. Geological Survey in deep-well observations, went at once to Findlay and recorded temperatures in the Norris well, the results of which are set forth in the following article. The writer also visited the locality and obtained the log of the well and samples of the drillings. In the Norris well no samples were saved until the "bottom of the Trenton" was reached at a depth of 2755. The samples from the succeeding 225 feet were donated by Mr. J. B. Maxwell, one of the drillers. Information concerning the higher strata was derived from the Grubb well, which reached a depth of 2470 feet. Credit is due Mr. J. E. Dougherty, the driller, who saved a complete set of samples which were given to the Survey. A duplicate set was also furnished by Mr. Berry of the Ohio Oil Company. Thanks are extended to Mr. Casterline, and especially to Mr. Fennerty of Findlay, for their courtesy and assistance.

The combined records of the Norris and Grubb wells are of unusual geologic interest as the drill passed below the base of the Paleozoic and penetrated pre-Cambrian rocks, concerning which nothing has been known heretofore in this part of the United States. There is given below a geologic section, which represents the combined well records. All but the lower 610 feet of the section presents data derived mostly from the Grubb

* Published by permission of the Director of the U. S. Geological Survey.

well record, with depths adjusted so as to coincide with those in the Norris well. This seems permissible, for the distance between the two wells is only a few miles. The question as to the age and relations of the various beds was discussed with Dr. E. O. Ulrich, of the U. S. Geological Survey, and the correlations used in the section are those suggested by him, adapted to the nomenclature and classification in current use by the U. S. Geological Survey.

Limestone of Niagaran age forms the surface in the vicinity of Findlay. This is generally covered with 10 to 100 feet of glacial drift. In the Grubb well this limestone was found 311 feet thick. The underlying strata in descending order are shale and brownish gray limestone of either Clinton or upper Medina (Ohio "Clinton") age; then gray and red shale, probably to be correlated with the lower Medina on the one hand and the Richmond on the other, underlain in turn by gray and brown shales with a thickness of 732 feet, representing the lower formations of the Cincinnati series. The top of the oil-bearing limestone, generally known as Trenton, was struck at 1165 feet and the drill continued in limestone and shaly beds, probably of Black River, Lowville, and Stones River age, to a depth of 1894 feet, giving a thickness of 729 feet for these strata. Then comes 406 feet of white, granular quartzose limestone and sandstone, all of which probably represents St. Peter sandstone. At 1135 feet below the top of the "Trenton" is a dark, glauconitic, dolomitic limestone 60 feet thick that is referred to the Upper Cambrian. Beneath this is garnetiferous, arkosic sandstone, which was penetrated only 10 feet in the Grubb well. Its thickness, as shown by the Norris record, is 395 feet. All of it is probably Upper Cambrian. At the base of the sandstone is 15 feet of red, green, and gray clay, which rests upon granite. Drilling was discontinued after the granite had been penetrated to a depth of 210 feet.*

*The "Trenton" limestone was found at a depth of 1165 feet in the Norris well, and the base of the garnetiferous sandstone (bottom of the Grubb well) at 2755 feet. As has already been stated, no samples were saved in this portion of the well, but the drillers report a uniform, gray grit throughout the interval. The belief that the lower 395 feet of the section is entirely sandstone is corroborated by the mineralogical examination of samples collected from the sand cone back of the derrick where the pumpings were dumped. A cut was made through this cone and thus a condensed section showing the principal beds in inverted order was obtained. Immediately underneath the granite drillings were the thin films of gray, green and red clay, mentioned; then came several inches of rusty gray sand which corresponds to the thick Upper Cambrian sandstone. The greater part of this was clean and contained a few accessory minerals. A little deeper in the sand cone was a dark band which represented the dark Upper Cambrian dolomite.

Geologic section of wells at Findlay, Ohio.

	Depth in feet	Thick- ness
Glacial drift	0-87	87
Silurian :		
Niagaran strata :		
(c) Limestone, dark gray, slightly dolo- mitic, dense textured	87-134	47
(b) Limestone, gray, crystalline, slightly dolomitic	134-195	61
(a) Limestone, dark, minutely crystalline	195-245	50
Strata of Medina or Clinton age :		
(b) Shale, calcareous	245-255	10
(a) Limestone, pinkish, brownish, and gray ; minutely granular texture (probably Ohio "Clinton")	255-343	88
Ordovician :		
Cincinnatian series :		
Strata probably equivalent to Richmond and lower Medina :		
(b) Shale, grayish	343-399	56
(a) Shale, red	399-433	34
Strata of Maysville, Eden, and Utica age :		
(b) Shale, a gray to dark gray, unusually pure clay shale. Some parts resem- ble flint clay. Grit is almost want- ing. Scattered particles of marcasite present. A slight flow of gas report- ed at 770 feet in Norris well. No fossils were seen. (Maysville and upper Eden.)	433-965	532
(a) Shale, dark brown, calcareous, very fossiliferous. A species of <i>Dalma- nella</i> was the only form recognized. The age of the beds is probably Utica and in part Eden	965-1165	200
Mohawkian series :		
(c) Limestone (Trenton ? or Galena ?), highly dolomitic, brownish gray, granular texture, having numerous cavities lined with crystals of dolo- mite and marcasite. In the Grubb well there was a show of oil 23 and 46 feet below top and salt water at 40 feet which rose 200 feet. This is the "Trenton oil rock" of northwest- ern Ohio	1165-1233	68
(b) Limestone, slightly dolomitic, vary- ing from dark gray to nearly black, dense textured. Some shaly beds. Fossils are plentiful, and indicate Black River age	1233-1325	92

	Depth in feet	Thick- ness
(a) Limestone, light gray to dark gray, minutely crystalline; no fossils seen, but probably of Lowville age.....	1325-1401	76
Lower Ordovician series:		
Strata of probable Stones River age:		
(e) Limestone, dense textured, dark....	1401-1637	236
(d) Limestone, light gray, minutely crystalline.....	1637-1675	38
(c) Limestone, dense textured, dark, becoming brownish near base. Some shaly beds present. Show of oil near top in Grubb well. These limestones are devoid of fossils and vary from light dove color to dark bluish. The texture is smooth. Some portions are argillaceous and resemble lithographic limestone.....	1675-1850	175
(b) Shale, bluish green, slightly calcareous.....	1850-1875	25
(a) Limestone, dark gray.....	1875-1894	19
Strata of probable St. Peter age:		
(i) Limestone, dolomitic, white, granular with quartz grains in lower portion. In the Norris well a little oil was found distributed through the rock at a depth of 1900 to 1960 feet, and at 1990 feet was the "Blue Lick" water which rose 1200 feet..	1894-2085	191
(h) Sandstone, calcareous, white. Quartz grains well rounded and assorted....	2085-2105	20
(g) Limestone, white, slightly dolomitic, minutely granular. Some quartz grains present.....	2105-2155	50
(f) Sandstone, with calcite, microcline and orthoclase as prominent accessory constituents.....	2155-2195	40
(e) Limestone, slightly dolomitic, white, siliceous, minutely granular.....	2195-2229	34
(d) Sandstone, with much calcite. Quartz grains rounded, average diameter 0.4 ^{mm}	2229-2239	10
(c) Limestone, dolomitic, dark gray, sandy.....	2239-2255	16
(b) Clay, green.....	2355-2260	5
(a) Sandstone, with few accessory minerals besides calcite. Quartz grains show secondary enlargement.....	2260-2300	40

	Depth in feet	Thick- ness
Upper Cambrian :		
(c) Limestone, dolomitic, dark, minutely granular. Much green glauconitic material and some quartz. Basal portion sandy and brownish gray. Some of the rock particles have veinlets of calcite	2300-2360	60
(b) Sandstone, impure, arkosic in upper portion. Garnet, orthoclase, microcline, and plagioclase are plentiful. Usual diameter of grain 0.3 to 0.5 ^{mm} . Samples from the Norris well show a white sand of angular grain that drilled fine, indicating a quartzite..	2360-2755	395
(a) Clay, top portion red, middle green, and base gray	2755-2770	15
Pre-Cambrian :		
Granite, probably gneissoid. Biotite and green hornblende principal accessory minerals, with a considerable amount of titanite and apatite and a lesser amount of garnet	2770-2980	---

A deep well drilled at Waverly in southern Ohio is of interest in this connection, and a condensed section with major headings omitted is given for comparison. The record was studied by R. S. Bassler, whose description appears in volume xxxi of this Journal, pages 19-24.

Geologic section of the Waverly well.

	Thickness in feet	Depth
Fine grained drab sandstone, forming lower part of Waverly series	35	0-35
Bituminous, fissile black Ohio shale	450	35-485
Mainly white, fine-grained sandstone with traces of white limestone. Red and brown calcareous sandstones of Clinton age in basal portion	415	485-900
Blue shale and fragments of blue limestone, Richmond and Maysville age, with probably upper Eden shales represented	1065	900-1965
Blue shales containing Middle Eden fossils ...	55	1965-2020
Unfossiliferous blue and greenish shale, probably lower Eden and Utica	80	2020-2100
Blue clay and shale with a few fragments of blue limestone. Lower Trenton fossils noted ..	125	2100-2225
White, clayey, and dove-colored unfossiliferous limestones and blue argillaceous limestone at bottom (Lowville and Stones River)	600	2225-2825

	Thickness in feet	Depth
White, saccharoidal sandstone (St. Peter)	175	2825-3000
White, dolomitic limestone. Fragments of igne- ous rock at base	320	3000-3320

The following section is regarded by Dr. Bassler as representative of the region near Cincinnati. It was taken from a well drilled at Oxford, described by Joseph F. James in volume x of the Journal of the Cincinnati Society of Natural History. The correlations are inserted in brackets by Bassler in the article cited, and the original classification of James is omitted.

*Geologic section of well at Oxford, Ohio.**

	Thickness in feet
Blue limestone and shale [Richmond and Maysville]	360
Blue shale [Maysville and Eden]	380
Dark limestone [Trenton]	50
White limestone with magnesia [Lowville and Stones River]	495
White, arenaceous limestone [St. Peter]	40

It is pointed out by Dr. Bassler that the Maysville and Richmond do not vary greatly in thickness across the Cincinnati arch, but that the great variation in thickness of the Cincinnati series is probably due to an increasing thickness of Utica shale away from the apex of the axis. He also says:†

"The same eastward increase in thickness for the Trenton rocks may be stated with less doubt. At Cincinnati the lower 50 feet of the Trenton are exposed with the thin Utica shale resting upon its eroded surface. Proceeding southeast along the Ohio River, this thickness increases to over 100 feet, in a distance of 30 miles, by the addition of higher beds of the formation. The occurrence of 125 feet of Trenton strata at Waverly 80 miles east, is, therefore, in line with the idea that the Trenton and the Utica are alike in having a minimum thickness along the Cincinnati axis."

The thickness of the lower formations of the Cincinnati series at Findlay and other localities in northwestern Ohio, is shown by well records to range from 700 to 1000 feet, being 732 feet at Findlay, and over 950 feet at Carey in Wyandot County. Records in Van Wert, Allen, Hancock, Wyandot, and Wood counties, all show a bluish gray shale in the upper portion and beneath this a calcareous, brown, fossiliferous shale which everywhere varies only a little from 300 feet in thickness. It seems probable that this brown shale is the equivalent of the Utica and at least a portion of the Eden shale of the Cincinnati region.

* This Jour., 4th ser., vol. xxxi, p. 22.

† Op. cit., p. 23.

There is nothing in the Findlay well records which proves the presence of the Point Pleasant formation as developed in southern Ohio, which contains a Trenton fauna. The oil-bearing limestone underlying the Utica (?) shale and popularly known as the Trenton may be the equivalent of the Galena limestone which is of early Trenton age. The rock is a brown, crystalline, open-textured dolomite with numerous voids. These are lined with dolomite crystals and marcasite, which appears to be the latest mineral introduced. This open-textured oil- and water-bearing dolomite has a thickness of 68 feet. Beneath it is a dense, dark gray limestone having numerous fossils. A diminutive variety of *Dalmanella testudinaria* is especially significant, and Black River is indicated as the probable age of the beds.

The drillers report sharp sands which cut the drill, at depths of 85 and 180 feet below the top of the "Trenton," but an examination of the samples showed but little quartz within those limits. The limestone of Black River age has some shale beds. The limestones considered to be of Stones River age are more or less argillaceous and even textured, and vary from light dove color to nearly black. They appear to be devoid of fossils. There is some shaly limestone in the lower portion.

The white granular limestone immediately under the limestone last described occupies the position usually assigned to the top of the St. Peter. The samples from the upper portion contain little quartz and the first sandstone bed penetrated lies 150 feet lower. The succeeding 190 feet consist of alternating layers of siliceous limestone and white sandstone, with a thin layer of clay near the base. This gives the unusual thickness of 406 feet for the St. Peter.

Some oil was found in the Norris well in the interval ranging from 1,900 to 1,960 feet in depth. This may have come from the lowest bed tentatively assigned to the Stones River, but it seems more probable that the horizon belongs in the St. Peter. No oil was reported at this horizon in the Grubb well. The "Blue Lick" water, a bittern characteristic of the St. Peter, was found about 30 feet lower than the oil.

There is little doubt that the dark dolomitic limestone found at 2,300 feet is Upper Cambrian. No recognizable fossils were discovered, but the rock has an abundance of glauconite. The underlying sandstone having a thickness of 395 feet rests on pre-Cambrian rock.

The pre-Cambrian rock was penetrated to a depth of 210 feet. The water from the overlying sandstone was cased off, and it was necessary to pour in water to facilitate drilling. Progress was slow in the hard rock which played havoc with the drill. The bailer was run four times each day giving

samples at intervals of three or four feet, which were painstakingly washed by the driller thus losing all of the mineral powder. No rock particles were obtained.

The samples, fifty-five in number, are fairly uniform as to mineral composition except the ones from near the bottom of the hole, which consist largely of flakes of iron and heavy minerals. Quartz and feldspars are the principal constituents. The feldspars are principally orthoclase, microcline and acid plagioclase. A few microperthitic intergrowths were seen. The quartz has inclusions of rutile. Green hornblende and biotite are next to quartz and feldspar in order of abundance. These are not uniformly distributed, being abundant in some samples and practically wanting in others. Such irregularity in their occurrence may signify a banded gneissoid structure for the rock, but it must be remembered that the sand bailer is not an accurate sampling device, and in dumping, mica and hornblende would be the most likely materials to be washed away and lost. Minerals present in lesser amounts are titanite, apatite, garnet, muscovite, zircon, and a mineral probably diopside, together with chlorite, sericite, kaolinite, and other alteration products. There are several rusty oxidized samples from various depths which evidently came from shear zones or joint planes, but aside from these decomposition is not advanced even in the upper portion.

Garnet is found rather sparingly in the upper portion, but the samples at and near the bottom of the hole have much garnet, together with zircon, titanite and other heavy minerals. Titanite is more plentifully and uniformly distributed throughout the rock, and in some samples probably constitutes as much as four per cent. Muscovite is present in only a few samples. One sample, lacking hornblende and having considerable muscovite and little biotite, may have come from a pegmatite dike.

The information at hand does not warrant sweeping conclusions as to the relations of this rock, but it is believed that its composition is consistent with that of granite. In the upper portion the rock is typical hornblende granite. Toward the bottom the quantity of dark minerals becomes larger, but is not prohibitive, and it is doubtful whether the name granodiorite should be used even for this most basic portion. The somewhat abundant occurrence of titanite and garnet might be regarded as militating against the conclusion that the rock is igneous, but these minerals may be accounted for by supposing that sedimentary masses were caught up and blended with the granite magma. This view is supported by the fact that these minerals are more or less localized.

It is probable that the rock has a gneissoid structure. No evidence of this was noticed in the microscopic examination of the samples, but there is an alteration of light and dark samples which suggests a banded rock.

ART. XIV.—*Note on the Temperature in the Deep Boring at Findlay, Ohio*; * by JOHN JOHNSTON.

AT the instance of the U. S. Geological Survey the writer went to Findlay, Ohio, in order to make a series of measurements of the temperature at various depths in the bore-hole, the geology of which is discussed in the preceding paper by Mr. Condit. The results obtained are communicated in the present note.

The temperatures were measured by means of maximum-reading thermometers† which, with a scale extending from 0° – 100° C., were divided into single degrees, the length of each of which was about 1.4^{mm} . These thermometers had been previously calibrated at the Bureau of Standards and found not to be in error by more than 0.1° C., which is the limit of practicable accuracy with such thermometers and is moreover ample for the present purpose. Now if only a single thermometer is used, accidental jarring of the thermometer sustained while it is being raised to the surface may lead to errors the existence of which might not be detected; in order to eliminate this possibility of error, three thermometers were always used together. As a matter of fact the readings of all three thermometers were in each case concordant, showing that freedom from jarring was attained by means of the thermometer cage made use of.

This cage consists essentially‡ of a thin-walled open copper tube, slightly constricted at the lower end, suspended between two spiral springs which were fastened to a sort of cage made of stout wire; this in turn was attached top and bottom, by means of open links, to 100 foot lengths of one-eighth inch steel wire cable. The thermometers, which in this case were armored, were held fast in the copper tube by short pieces (1 inch) of rubber tubing of appropriate size slipped about one-half inch over either end of each thermometer and kept in compression between the constricted lower end of the copper tube and a kind of hinged lid at its upper end. The lower thin steel cable carried a weight; the upper was attached to the bottom of the bailer, which in turn hung as usual on the sand line and was raised and lowered by means of the engine. The use of a weight is advisable, as in its absence there is likely to be considerable jarring of the thermometers; the weight must

* Compare the preceding paper by Mr. Condit.

† Obtained from H. J. Green, 1191 Bedford Avenue, Brooklyn, N. Y.

‡ A full description of the apparatus, and a discussion of methods of accurately determining temperatures in bore-holes, will be published later.

of course be so far below the thermometers that the heat absorbed by it is not abstracted from the zone the temperature of which is desired. Likewise the thermometers should be a considerable distance below the bailer, which is a convenient means of minimizing any convection currents which might perchance be present.

There are a number of circumstances which affect the temperature of bore-holes; we cannot discuss them here, but shall point out one or two of the more common conditions likely to cause errors. Temperatures at the bottom of a hole should

FIG. 1.

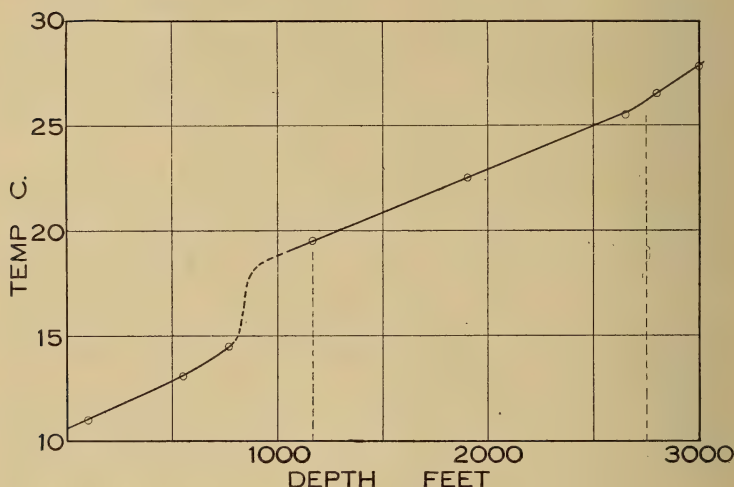


FIG. 1. Curve showing the relation between observed temperature and depth in the bore hole at Findlay, Ohio.

not be taken until at least twenty-four hours have elapsed since drilling was discontinued or since water was poured in the hole; otherwise it is uncertain if the temperatures observed really represent the temperature of the rock at the depth in question. Moreover the temperature of water brought up in the bailer is no certain criterion of the temperature down below, for if the bailer is raised quickly, the friction against the casing may be sufficient—in deep wells, especially—to produce a temperature actually higher than that obtaining down at the bottom of the hole. But the factor which perhaps intervenes most frequently and most seriously in the attempted determination of the temperature of the rock (as distinct from that of the air or gas in the hole) is the flow of gas, which in

expanding cools itself off.* Its influence is evident in the present series of measurements, which, therefore, do not

Temperature at Various Depths in the Borehole at Findlay, Ohio.

Depth in feet.	Period of immersion of thermometer Hours.	Temperatures observed.		Corrected average temperature.		Remarks.			
		Thermometer number.	Reading : Degrees C.	Centigrade.	Fahrenheit.				
100	18	1	11.0	11.0	51.8	} Top of "Tren-ton."			
		2	11.0						
		3	11.0						
550	1½	4	13.0	13.1	55.6		}		
		5	13.2						
		6	13.1						
770	1	4	14.5	14.5	58.1			}	
		5	14.6						
		6	14.5						
1165	1½	4	19.4	19.5	67.1				}
		5	19.5						
		6	19.6						
1165	1	4	19.3	19.4	66.9	}			
		5	19.4						
		6	19.5						
1900	1½	1	22.5	22.5	72.5		}		
		2	22.5						
		3	22.4						
2650	1½	4	25.4	25.5	77.9			}	
		5	25.5						
		6	25.6						
2800	1½	1	26.5	26.5	79.7				}
		2	26.5						
		3	26.4						
2980	18	4	27.8	27.8	82.1	}			
		5	27.9						
		6	27.8						

represent the temperatures of the *rock* at horizons above that of the gas in flow.

* It is, of course, self-evident that no definite conclusions of value can be drawn from temperature measurements in wells in which there is a flow—even a small flow—of oil or water.

The actual results are presented in the above table. The depths were determined by measuring down the sand line, a method which is of ample accuracy for the present purpose. The first trial was made at a depth of 1165 feet, the thermometers being left at that level for one and one-half hours, and in a second trial for one hour only; the concordance of the results thus obtained shows that, with the form of apparatus used,* a period of one and one-quarter hours sufficed substantially for the attainment by the thermometers of the temperature of the zone in which they were placed. This is confirmed by the agreement between the measurements made with a period of one and one-quarter to one and one-half hours and those in which the thermometers were left overnight in the hole; as is evident from the figure, in which temperatures have been plotted against depths.

The figure shows very plainly the general regularity of the results, apart from the marked discontinuity which was observed, as might be expected, at the point at which gas appears. The temperatures observed at depths less than 770 feet do not represent the temperature of the surrounding rock, but that of the atmosphere in the well, which is cooled by the flow of gas between the outer and inner casing of the well. The temperature gradient in the sedimentary rocks from the "Trenton" limestone downward is about 0.41°C . (0.74°F .) per 100 feet; that in the crystalline rocks appears to be somewhat higher, but the data are insufficient to enable one to draw any very certain conclusions from this phenomenon.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C., June, 1913.

* The period required for the practical attainment of temperature equilibrium between thermometers and the surrounding rock depends of course upon the form and weight of the cage surrounding the thermometers and should always be determined by actual trial.

ART. XV.—*The Arc Spectrum of Tellurium*; by H. S.
UHLER and R. A. PATTERSON.

THE object of the present paper is to give an account of the results of our experimentation upon the arc spectrum of tellurium and to place on record the wave-lengths of the arc lines on the basis of the international system. The attention of the senior author was directed to the interesting and apparently anomalous behavior of tellurium with respect to the Mendeléeff table during the winter of 1910–11 by Professor Philip E. Browning at the time when Doctor William R. Flint was working, in the Kent Chemical Laboratory, on the problem of the complexity and atomic weight of tellurium. At that time the primary object in the spectroscopic work was to test the purity of Flint's material. In order to avoid gas lines and to obtain the spectral lines as sharp as possible the electric arc was used instead of the spark. Also to save the metal and to prevent oxidation the arc was formed in a specially constructed brass cylinder through which a current of carbon dioxide gas was kept flowing. The grating then employed had a radius of curvature of about ten feet, 14,436 lines per inch, and it was ruled by Schneider on one of Rowland's engines. Since the mass of each of Flint's most important by-products was small, a little preliminary work showed that the spectrograph was too large for the object then in view. Consequently the problem of testing spectroscopically the composition of these by-products was deferred until more suitable apparatus could be obtained. Nevertheless, it may be stated that the arc between comparatively pure electrodes of metallic tellurium could not be maintained continuously at about 110 volts in hydrogen, or in carbon dioxide, or in air. In fact, the carbon dioxide seemed to be partly reduced because the spectrograms showed all the strong lines of carbon and a black deposit, which may have been finely divided graphite, was formed on the electrodes. Especial care was not taken to purify the carbon dioxide as was made evident by the presence on the negatives of the band at $\lambda 3590$, which is usually ascribed to cyanogen.

Since the time mentioned above we have been so fortunate as to obtain two concave gratings ruled by Professor John A. Anderson on Rowland's remodelled engines. The smaller grating is the best we have ever seen and the larger one is of the highest grade. The former has a radius of curvature of one meter and 18,159 lines in the space of 4.60 cm . It is mounted in essentially the same manner as was the grating set

up by one of us to obtain the data for the "Atlas of Absorption Spectra"*. The larger grating has a radius of curvature of about 21.5 feet and 15,000 lines per inch. It is mounted according to Rowland's plan. With these two spectrographs we have been able to test Flint's material successfully and to investigate the arc spectrum of tellurium. The latter problem being the more important and fruitful will be taken up first.

With the smaller instrument films sensitized by the "Pan-chromatic B" emulsion of Wratten and Wainwright were used. We found these films to be uniformly sensitive from about λ 2300 to λ 6500. With long exposures or with very intense radiations it was possible to photograph between the limits λ 2000 and λ 7200. With the larger apparatus Cramer "Crown" and "Instantaneous Isochromatic" plates were employed. The simple hydrochinone developer as formulated by Jewell was used throughout.

When the work was begun we could only find four arc lines of tellurium recorded. These were measured by Exner and Haschek. When the sixth volume of Kayser's "Handbuch der Spectroscopie" reached us it added three more arc lines, as determined by Eder and Valenta. These seven lines are all in the ultra-violet above λ 2800 and yet the arc produced by bringing in contact and quickly separating two rods of metallic tellurium is so intensely bright as to suggest the existence of radiations in the visible region of the spectrum. The hypothesis that this light was due entirely to incandescent solid or liquid tellurium did not seem adequate. For this reason, as well as on account of the fact that certain articles in chemical journals imply that some of the tellurium lines coincide exactly with the lines of other elements, we decided to investigate the arc spectrum as if nothing were known about it in advance. The problem consisted, therefore, in two parts, first, the determination of all the lines which pertain to the arc spectrum of tellurium and only to this substance and, second, the measurement of the wave-lengths of the arc lines in terms of the interferometer standards.

Obviously, the meter-radius grating was employed to attack the first part of the problem. To have a sure foundation of comparison, negatives were taken of the arc spectra of all the metals, 17 in number, which were likely to occur as impurities in the metallic tellurium or in the oxides and nitrates of this element. Selenium does not give an arc spectrum and hence it presents no difficulty as far as the lines of tellurium are concerned. On the other hand, selenium affords an example of a substance which would escape detection if the arc alone were used in analyzing spectroscopically

* H. S. Uhler and R. W. Wood, Carnegie Publication No. 71 (1907).

a mixture which might contain it. The metals or suitable salts were placed in shallow holes which had been drilled in the lower, positive, carbon electrodes. The carbon rods were made and regraphitized by the Acheson Company of Niagara. Although these electrodes contained only slight traces of impurities, "blank" exposures were taken for each rod. Six negatives were taken on each film. Fifteen lines have been absolutely identified as belonging to the arc spectrum of tellurium. All of these lines are in the ultra-violet above $\lambda 3200$ and they have all been observed in the *spark* spectrum by other investigators. To avoid repetition of the wave-lengths the lines will be referred to by the arbitrary numbers in the first column of the following table.

No.	Wave-lengths	Intensity	Character
1	3175.130 Å	9	sharp, narrow reversal
2	2769.653	9	" " "
3	2530.734	7	" " "
4	2431.771	1	fine, sharp
5	2420.122	1	" "
6	2385.783	10	broad, wide reversal
7	2383.268	10	" " "
8	2265.515	5	sharp, narrow reversal
9	2259.02	8	broad, wide "
10	2255.50	5	sharp, narrow "
11	2208.88	6	"
12	2160.12	6	"
13	2147.33	8	"
14	2143.0	9	broad, wide reversal
15	2081.8	8	sharp

By means of the meter grating, lines 1 and 2 were readily proved to belong to tellurium, although they seemed to coincide with the lines $\lambda 3175.044$ and $\lambda 2769.939$ of tin and antimony respectively. In other words, lines 1 and 2 were always present in the arc spectrum of tellurium when not the slightest trace of the strongest lines of tin and antimony could be seen on the negatives. Since line 1 is not very wide, since its wave-length differs from that of the tin line by only 0.086 Å, and since the tin line in question is one of the most intense and broad arc lines of this element, it is not surprising that line number 1 has been overlooked by earlier investigators. When the fuzzy spark lines are photographed, the quartz spectrographs employed by Köthner and others

would probably not suffice to separate the antimony line from line 2, the interval being about 0.29\AA . [$\lambda\ 3175.044$ is according to our measurements whereas $\lambda\ 2769.939$ is quoted from volume VI, page 440, of Kayser's "Handbuch." It was measured by Schippers.]

In the later work we were given such large quantities of especially purified metallic tellurium by Professor Browning as to enable us to dispense with the enclosed-arc apparatus and to work in air in the usual manner. Between 45 and 110 volts D. C. it was not possible to maintain an arc between rods of pure tellurium. The small spectrograph showed that, in addition to the ultra-violet lines, the arc formed at the instant of breaking the circuit radiates a continuous spectrum between the limits $\lambda\ 3300$ and $\lambda\ 4800$. This accounts in part only for the visible light mentioned above. It seems to come from the vapor and not from the electrodes directly. However, we have not fully proved this point. If this continuous spectrum is really made up of bands then they are too fine and uniform to be resolved by the small grating. The intensity of the continuous spectrum was not sufficient to justify trying to record it with the largest spectrograph. With this instrument the arc was always obtained by putting lumps of the metal in a shallow hole in the lower, positive, graphite electrode. The arc would not burn between the pointed lower end of the negative electrode and the large, spheroidal globule of tellurium but it would wander around the peripheral line of contact of the lower electrode and the globule. The arc is intensely white and it shows the various arc-regions (core, mantle, etc.) very clearly and beautifully. Of course, when using an arc of tellurium in the manner just mentioned, special precautions have to be taken to avoid breathing the fumes which are injurious and very irritating to the nose, throat and lungs.

Lines 1 to 10 inclusive were photographed in the second order of the largest grating. The iron spectrum was always impressed simultaneously with that of tellurium, and care was taken to have the grating entirely filled with light. Also, each line was photographed at the center of curvature of the grating in order to have the interferometer iron lines distributed nearly linearly. The spectrograms for lines 1 to 10 inclusive were measured either two or three times in one direction and then an equal number of times when reversed. The same lines were measured on different plates by the two observers and the means of the separate wave-lengths are given in the above table. In general, the results agreed very closely, but, because some of the interferometer lines used have only been determined by Fabry and Buisson and also because there exists at the present time some doubt as to the constancy of

the wave-lengths of the iron lines, we are of the opinion that 0.005 Å is a fair estimate of the possible error of our results for lines 1 to 8 inclusive. Lines 9 and 10 were so faint in the second order as to preclude the possibility of measuring them closer than 0.01 Å. Their wave-lengths were checked up in the first order. Line 11 was also measured in the first order of the largest grating, whereas lines 12 to 15 could only be obtained with Σ Lumière plates in the first order of the 10 ft. grating and with Panchromatic films in the same order of the meter spectrograph.

As to the arc lines themselves the following remarks may not be superfluous. By using some metallic tellurium which contained a trace of tin as an impurity an excellent negative was obtained, in the second order of the largest grating, which showed the iron, tin and tellurium lines very sharp and fully resolved. The wave-lengths are 3175.044, 3175.130 and 3175.447 for tin, tellurium and iron in the order named. This removes all doubt as to the independence of the tin and tellurium lines. In like manner the antimony and tellurium lines at 2769.94 and 2769.653 were differentiated. Lines 6, 7, 9, and 14 were broadly and symmetrically reversed, in general, and they seem to belong to a class by themselves. Line 6 was always wider and a little more intense than line 7. Lines 4 and 5 were never obtained reversed or double with the two larger gratings. Strange to say, when the films were examined with a compound microscope each of these lines appeared to be double. The duplicity seemed to be due to self-reversal because the separation of the components varied from film to film. The reversal is asymmetric, but in some cases the longer wave-length component is the weaker, and in others just the opposite holds. The reversal was wider when a pure salt was tamped in the lower electrode than when the metal alone was used. Salts were not used with the largest grating. Lines 11, 12, 13, and 15 never appeared reversed on the negatives. All the remaining lines were easily obtained with fine, symmetrical, axial self-absorption. As might be expected, the reversal of any one line is widest at the end corresponding to the positive, lower electrode.

Because other investigators have been unable to repeat the work of Flint in such a manner as to obtain his low value for the atomic weight of tellurium, it may not be superfluous to state the results of our spectroscopic analysis of the specimens which he left with one of us in the spring of 1911. The white needles which corresponded to the atomic weight 127.45, when vaporized in the arc, showed only slight traces of antimony and copper. It must be remembered, however, that some elements such as selenium do not give lines in the elec-

tric arc. The crystals in the vial labelled "alpha sub. 8., at' w't. 126.6" seemed to be as pure as the 127.45 material. The same statement applies to the sample marked " TeO_2 .124.3 Redistilled fraction 10". One negative showed more copper for 124.3 than for 127.45, but another negative did not. Consequently the discrepancy must be ascribed to slight, unavoidable changes in the conditions of the arc. The orange-yellow crystals ("beta. P' p't. by NH_4OH and boiling") gave a fairly complete spectrum of iron. From the spectroscopic standpoint we would say that a great deal of iron was present. The usual trace of copper was recorded. At our request Professor Browning subjected some of the yellow crystals to a delicate chemical test for iron and found this metal to be present, thus verifying our analysis. However, he did not think that the percentage of iron was at all great. The test seems to have been definite but not pronounced. These results are at variance with Doctor Flint's statement that "No slightest traces of either iron or copper can be discovered by the usual tests"*. There was no discernible difference between the metallic tellurium which had been distilled once and twice in hydrogen. The lines of sodium were very strong and there were some lines of antimony, iron, and lead. Copper was not at all strong. It would seem, therefore, that the particular process of distillation used by Flint is illusory.

In conclusion we desire to state that our work on the spectroscopic properties of tellurium will be continued during the next academic year. Also we desire to express our sense of deep indebtedness to Professor Browning for having supplied us with the large quantities of tellurium.

Sloane Physical Laboratory, Yale University,
New Haven, Conn., June, 1913.

* This Journal, vol. xxx, p. 219, Sept., 1910.

ART. XVI.—*The La Paz (Bolivia) Gorge*; by HERBERT E. GREGORY.*

FROM the shores of Lago Pequeno, the nearly enclosed south-eastern portion of Lake Titicaca, the surface of the interior plateau of Bolivia (the *altiplano* or *altiplanicie* of the Spanish Americans) ascends toward the Cordillera Real. From Guaqui to Viacha, forty-two miles, the rise is 120 feet and the railroad, after following the irregular course of the Rio Tiahuanaco and

FIG. 1.



FIG. 1. View from Alto looking eastward toward the Cordillera Real. The position of the gorge, on the floor of which the city of La Paz rests, is indicated by the arrow.

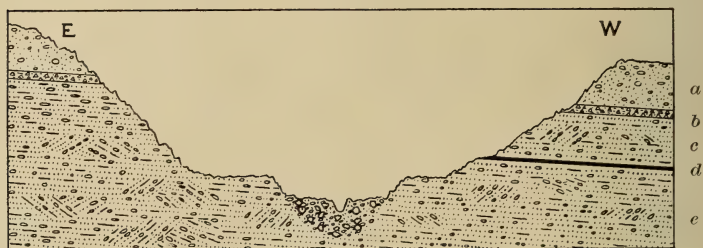
passing a group of low, mature hills, crosses the shallow valleys of the Rio Colorado and the Rio Viacha. From Viacha to Alto, the terminus of the steam railroad, the floor of the *altiplano* is remarkably flat, and slopes westward at the rate of forty feet per mile.† The drainage of this portion of the plateau is sluggish and frequently interrupted by shallow

*Geologist of the Peruvian Expedition of 1912.

† Distances and elevations are as shown on the Mapa General of the Ferro Carril del Sur del Peru, a blue print of which was kindly furnished by T. A. Corey, Chief Engineer.

depressions. No hills rise above the gravel-strewn floor which appears to extend as an unbroken surface to the foot of majestic Illampu. At Alto a surprise awaits the traveler, for here, without preliminary warning in change of slopes or eastward-flowing streams, one finds himself on the brink of a canyon cut entirely in alluvial deposits to a depth of over 1500 feet. At the foot of the canyon wall lies the city of La Paz, whose red tile roofs, cathedral spires and threads of streets, broken by parks and traversed by streams and irrigation ditches compose a unique picture of singular beauty.

FIG. 2.



a, gravel, sand. *b*, tuff. *c*, sands, gravel, clay. *d*, lignite. *e*, sands, gravel, clay.

FIG. 2. Generalized section of La Paz gorge, not drawn to scale.

As shown in the view (fig. 1), looking from Alto station across the La Paz valley, the landscape gives no suggestion of the presence of such a chasm and one is reminded forcibly of the Colorado Plateau of Arizona, where impassable canyons of great depth are revealed only when one is standing on their rim. On descending the canyon walls it is found that the floor is by no means flat, but is cut by streams which flow in gorges one hundred feet and more in depth, between and over which, resting on hills and terraces, the city is built. The larger part of the buildings are distributed along two more or less dissected terraces whose position with respect to the valley walls is shown diagrammatically in fig. 2.

Between San Jorge and Obrajes the La Paz river has sunk its bed into sands and clays whose eroded strata exhibit miniature "bad land" forms. Lying unconformably above these finer deposits at San Jorge and northward through the city are deposits of gravel which stand as nearly vertical walls fifty to one hundred and fifty feet high. The material is excessively coarse and contains boulders of white granite six inches to six feet in diameter. Above the gravel terraces, forming the knobs and benches and ridges of the western part of the

city as well as the walls of the valley, and extending nearly to the level of the *altiplano*, are beds of gravels and sands and clays eroded into a bewildering maze of forms. Needles in groups or singly, columns unadorned or fluted or capped by tables, rise five to fifteen feet on steep slopes and five to fifty feet on knife-edged, dividing ridges. Innumerable sharply-cut, miniature canyons with sheer walls five to two hundred feet in height together with tunnels and pits in great variety furnish passage for water. Landslides with slopes as great as 50° , frequently accompanied by open cracks, are numerous. Here and there benches and tables composed of cemented gravels and brown concretions project from vertical surfaces or form the capping of columnar masses. The whole deposit is ash-gray in general tone, but is beautifully striated by gray, brown, light pink, bright yellow, purple and white bands from a few inches to one hundred feet in thickness. Vegetation is absent except for patches of wiry grass and tough shrubs which find a foothold on the little flat-topped tables and gentler slopes. The beds in general dip slightly to the south.

A closer examination of the strata exposed reveals the presence of the following materials: (1) Sand, mostly fine, some coarse, composed chiefly of quartz grains, and arranged in beds several hundred feet in extent, or in short lenses. All the strata are more or less cross-bedded, with laminae dipping 0° – 25° . (2) Gravel, composed of rounded pebbles from the size of a small pea to three inches in diameter, arranged as lenses which exhibit marked and sudden variation in position and size both horizontally and vertically. The gravels are everywhere cross-bedded and frequently inclose lenses of sand. The component materials in the upper part of the section were found to consist approximately of sedimentary fragments 75 per cent, igneous 15 per cent, metamorphic 10 per cent. The following types of rock were recognized: gray sandstone, brown sandstone, white granite, granite-gneiss, diorite-gneiss, garnetiferous granite-gneiss, black slate, mica or chlorite slate, gray quartzite, brown quartzite. Quartz pebbles are rare and no limestone or volcanic material was observed. All the pebbles are worn, about half of them well-rounded, and a few are faulted and veined. The gravel increases in amount and becomes coarser toward the top, and along the electric railway from La Paz to Alto contains angular, sub-angular and rounded boulders four inches to one and one-half feet in diameter. At this locality the gravel forms beds of considerable thickness or occurs as lenses embedded in finer gravels, sands and clays, and resembles morainal deposits except for the irregular stratification. (3) Clays, rarely pure, usually highly arenaceous, generally distributed as lenses within the finer sands. In the

localities studied by the writer, clay is relatively small in amount, the larger beds being 100 to 200 feet in length and of inconsiderable thickness. (4) Carbonaceous shale and two

FIG. 3.



FIG. 3. View of deposits in La Paz gorge, about one mile west of the American Institute.

layers or lenses of impure lignite three to six inches thick, composed of comminuted plant remains too fragmentary for determination. (5) Volcanic ash, eight to fifteen (at one point twenty or more) feet thick, extending as a continuous white

band for over two miles on the west side of the valley and reappearing on the east side at an elevation of about 12,600 feet. Microscopic examination shows the ash to be dacitic.

FIG. 4.



FIG. 4. View of deposits in La Paz gorge, about one and one-half miles west of the American Institute.

The general appearance of the deposits and the arrangement and alternation of strata are shown in figs. 3 and 4, with which, for purposes of comparison, is inserted a typical view of the Dakota bad lands (fig. 5).

The texture and structure of a portion of the beds taken about midway between the top and bottom are shown in fig. 6. Figs. 7 and 8 exhibit details and are fairly representative of a large number of occurrences.

The profound gorge of La Paz with its great accumula-

FIG. 5.



FIG. 5. View of Bad Lands, South Dakota. Photo by Darton, U. S. Geological Survey.

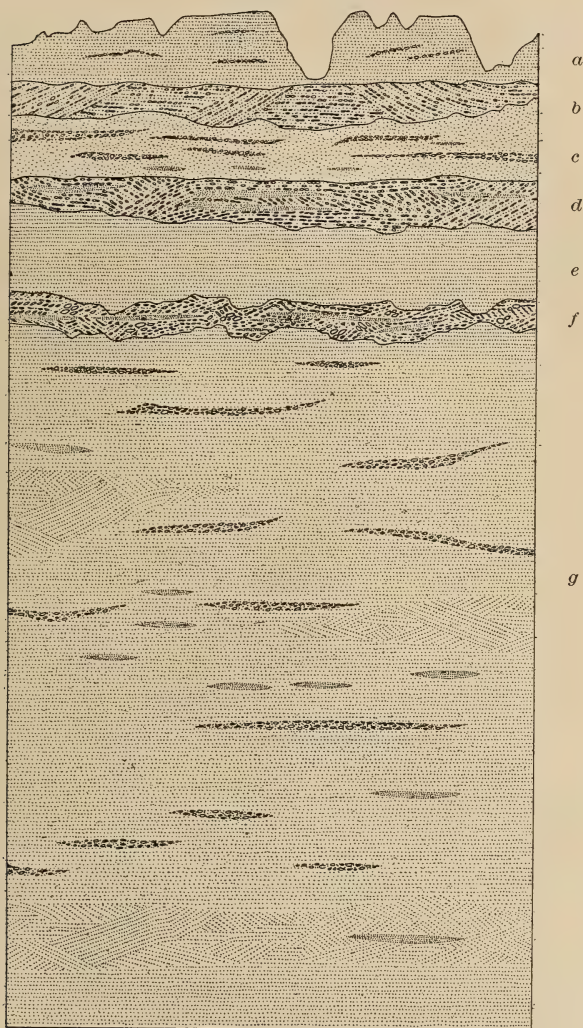
tion of unconsolidated sediments and striking erosion features has naturally attracted the attention of scientists and travelers alike. D'Orbigny* speaks of the La Paz deposits as "alluvial," and notes that sandstone pebbles were more abundant in the upper beds. He also recognized kaolin deposits at Miraflores,—a suburb not visited by the writer. Forbes† assigns

* Voyage dans Amérique Méridionale, Tomo III, 1842, partie 3, p. 120.

† Report on the Geology of South America, Quar. Jour. Geol. Soc., vol. xvii, 1860.

to these beds a thickness exceeding 2000 feet. The band of "trachytic tuff" "300 feet below the surface of the plain,"

FIG. 6.



a, 15 ft., fine sand with thin lenses of gravel. *b*, 4 ft., cross-bedded gravel. *c*, 24 ft., fine sand, consolidated in places and lenses of gravel. *d*, 14 ft., cross-bedded gravel, with lenses of fine sand. *e*, 20 ft., fine sand. *f*, 8 ft., cross-bedded gravel with lenses of fine sand. *g*, 200 ft., thin-bedded sands with gravel lenses; portions of sand firmly cemented.

FIG. 6. Section of a portion of the west wall of the La Paz gorge. Drawn to scale.

"20 to 30 feet in thickness," Forbes considered as part of a wide-spread "diluvial formation," occupying a basin between the Silurian rocks of the high Andes and the low Devonian hills to the west, and believed the impure lignite to be an extension of the carbonaceous strata exposed at the foot of Illimani and also near Poto-poto. The material composing

FIG. 7.

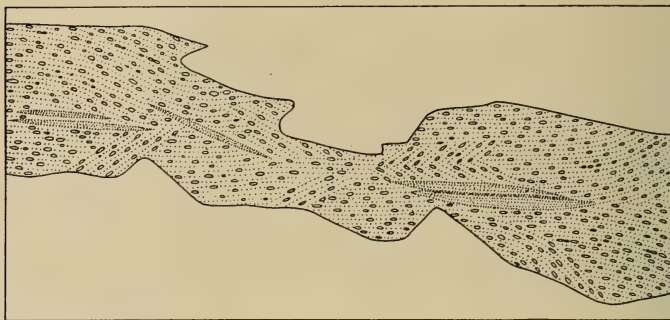
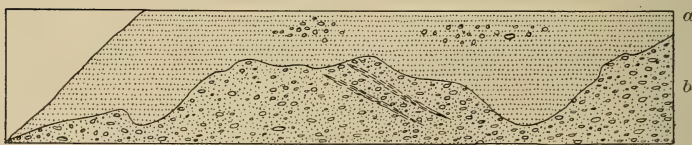


FIG. 7. Portion of gravel lens; extent and thickness of gravel and sand and orientation of cross-bedding laminæ drawn to scale.

FIG. 8.



a, sand with irregularly distributed gravel. *b*, gravel with two lenses of clay.

FIG. 8. Section on line of Arica-La Paz railroad, showing contact between gravel and sand. Drawn to scale.

these beds has its source, according to Forbes, in the Silurian strata of the Cordillera Real; with the exception of the volcanic ash, which he assumes had been carried by streams from Achacachi on the shores of Lake Titicaca. Zundt* assigns the

* Appendix to Spanish edition of D'Orbigny, La Paz, 1907.

granite bowlders to the Cordillera Real at the north, the quartz to the same area, and also to the mountains near Viacha and Colquencha to the west, clays to the Ramos formation (Tertiary?) underlying the *altiplano*, and the ash to the Letania mountains.

As to the condition of deposition of these deposits, D'Orbigny and Forbes appear to have held no definite views. Evans* expresses the opinion that "the enormous deposits of alluvium . . . represent not the alluvium of a lake, but the infillings of a longitudinal valley." Zundt† speaks of the ash deposit as carried by wind, dropped into a lake or sea and spread by the waves. Minchin‡ speaks of lake beds, a part of the floor of ancient Titicaca, now covered by glacial gravels. D'Arlach§ speaks of floods induced by earthquakes which cut the La Paz gorge and drained an interior sea. Posnansky|| apparently considers the base of the La Paz beds as marine-built, the upper portion deposited in an ancient sea detached from the Pacific by uplift. Zundt, whose previous views involved the existence of a salt sea, considers the deposits in the La Paz gorge as lacustrine,—the fillings of a temporary lake formed by blocking an ancient river which drained the interior basin. The upper end of the La Paz gorge is believed by this writer to have been excavated by glaciers. Bowman¶ recognized the fluvial origin of the La Paz beds, but in speaking of the deposits as "the coarsest alluvium, the sort of material that mountain torrents carry," evidently had in mind the upper beds of the section and the material forming the banks of the present stream, rather than the fine-textured, stratified deposits to the west and south of the city.

From the general and detailed sections described and figured above it appears that the deposits which line the La Paz gorge are in no way typical of lacustrine formations. The absence of continuous beds of thinly laid clays, silts and the finest sands of uniform texture, the presence of cross-bedding and channeling and the rapid alternation of gravels and sands both horizontally and vertically argue against deposition in the quiet waters of a lake. All the phenomena disclosed by the study of the sections may be accounted for on the theory that the region was traversed by low grade, piedmont streams. Such streams with a shifting net-work of distributaries and interlaced channels alternately depositing and cutting in a capricious manner

* Geog. Jour., vol. xxii, pp. 634-35, 1903.

† Loc. cit, 1907.

‡ Geog. Jour. vol. xxxvi, pp. 396-7, 1910.

§ Bol. Oficina Nacional de Estadística, No. 64-66, p. 756, La Paz, 1911.

|| Bol. Oficina Nacional de Estadística, No. 64-66, pp. 689-702, 1911.

¶ This Journal, vol. xxviii, p. 400, 1909.

in response to seasonal rainfall would produce just such sediments as the strata under discussion. Temporary lakes,—annual or lasting for decades,—are normal features of such a piedmont flood plain and are ample to account for the lenses of clay and the thin, short bands of carbonaceous material occurring in the section.

The geologic history of the La Paz gorge can not be written on the basis of the data at hand. The significance of the inner gravel terrace pointing to a second, or perhaps a third, cycle of filling and erosion, the conditions under which the remarkably coarse upper beds were deposited, the character of the floor on which the finer sediments were laid down, the extent of the deposits and the pre-glacial history of the La Paz river itself, are problems which will repay detailed physiographic research.

ART. XVII.—*Some Kilauean Formations*; by FRANK A. PERRET.

THE floor of the great pit crater of Kilauea has an area of more than ten million square meters, every one of which—on the surface, or immediately below it—reveals something of interest or importance to the investigator. To say, therefore, that a month might profitably be devoted to its exploration is almost to state an absurdity—a lifetime would be more appropriate and it is more than probable that, in such an interval, a new floor will have been laid, with fresh interests for the visitor at every step.

The larger portion, by far, of this great area is composed of pahoehoe lava which has overflowed from Halemaumau or welled up through more ephemeral vents—its smoothly undulating, glassy surface glistening with that satiny sheen which is responsible for the peculiarly expressive Hawaiian name. Here and there, however, a long, high-standing AA flow, having a jagged, dark red surface contrasting sharply with the surrounding plain, has made its way along some slight declivity from a now hidden vent from which it had issued tumultuously, hissing with gas at every pore. And, between these extremes, there may, in places, be found an intermediate type passing by insensible degrees from the most superficially incoherent AA to a form so smooth and plate-like as almost to merit the appellation “ultra-pahoehoe.”

In the opening sentence of the present paper a hint is conveyed of interesting things *beneath the surface* and that these exist is due to the fact that this great crater floor is composed chiefly of lava *flows*. A stagnant pool of the Kilauean lava will, in cooling, solidify from the surface to the bottom into a continuous and homogeneous mass of rock, but a flowing stream drains away, after the solidification of its surface layers, leaving a tunnel with an arched roof. The gases which continue to be emitted from the inner, flowing lava, undoubtedly assist in supporting the roof during consolidation and may even form expanded chambers at intervals along the line of a flow. On the crater floor the visitor is thus walking over caverns and tunnels of whose existence he is unaware, excepting in the comparatively few instances where the roof has foundered and revealed the “cave” below. The larger of these are provided with a ladder giving access to the interior and have been given fantastic names, such as “Pe’e’s Dining Room,” etc. In certain cases they have been observed by the writer to terminate upward in a prismatic cupola almost—and, in some

instances, quite—perforating the roof. If this occurs in the earlier stages of the flow, an active vent is formed, emitting much gas and a little lava in spatters or dribblets which build up a “blowing cone” over the orifice. When the action is violent, and especially if the cone has formed at or near the lava’s point of issue on the crater floor, it will take the form of an open cylinder, as in the case of the so-called “Little Beggar” (fig. 1), and the lava stream will then have the appear-

FIG. 1.



FIG. 1. The “Little Beggar” blowing cone.

ance of flowing from the base of the cone. A more moderate activity forms a simple “driblet cone” (fig. 2) in which the central conduit may be closed at the top by the last splashes emitted therefrom.

These spatter cones have always constituted a conspicuous feature of Kilauean volcanism and testify to the importance of the *gaseous emanations* from the active lava, upon which there has been so great a tendency to cast doubt. They are also interesting as demonstrating that the same, ultra basic lava which, flowing continuously, produces a cone with declivities so gentle as not to exceed, in some cases, four or five degrees will, if ejected intermittently in splashes which cement together and have time to cool, result in a construction whose sides may even attain the vertical and thus exceed the repose angle of the

most chaotic of fragmentary ejecta from more acid and explosive volcanoes. The cones often appear upon the newly formed "shore" of the Halemaumau lava lake and are then of the greatest value to the investigator as offering a means—by the introduction of a tube through an orifice of the blow-cone—of

FIG. 2.



FIG. 2. A typical spatter cone.

collecting the gases emanating directly from the active lava and before their modifications by contact with the air.*

Closely allied to the above-mentioned gas-expanded chambers along the line of a flow—and, in some instances, identical

* As has already been shown in preceding papers of the present series, these gases burn on coming in contact with the atmosphere.

with these—are the intumescent formations for which the late Dr. Benedict Friedlaender proposed the appellation “Schollendom” (fig. 3). In many instances these also are gas-expanded or, at all events, gas-supported, during solidification, and Mr. Immanuel Friedlaender has informed the writer of having observed these formations covering vegetation at the bottom of Kilauean-iki. Green has shown* how the characteristic subspherical shape may also result from the simple flowing out of pahoehoe lava in spheroidal masses, after the manner of por-

FIG. 3.



FIG. 3. A typical “Schollendom.”

ridge, upon which the surface cools over until the inner lava forces a way out at the lower side to flow on and form other spheroidal accumulations along the line of the flow.

On cooling, the mass is fissured by contraction and a central block is frequently separated from the rest and founders, revealing the dome in section—often as a comparatively thin roof arching over a void, but frequently also as a monolithic mass as deep as the dome itself (fig. 4).

It is, therefore, incorrect to state that these formations are intumescent by reason of the intrusion of fresh lava beneath a crust already formed and fractured—the Schollendom is a primary formation and is fissured by contraction in cooling. Intrusive lava often *does* uplift the flat slabs of the crater floor, the which are then incorporated with the resulting driblet mound,

* Wm. Lowthian Green : “ Vestiges of the Molten Globe,” vol. 2, page 173.

as could be shown photographically were the present paper not already overcharged with illustrations, but such a construction is not a true Schollendom. The writer has also seen already-

FIG. 4.

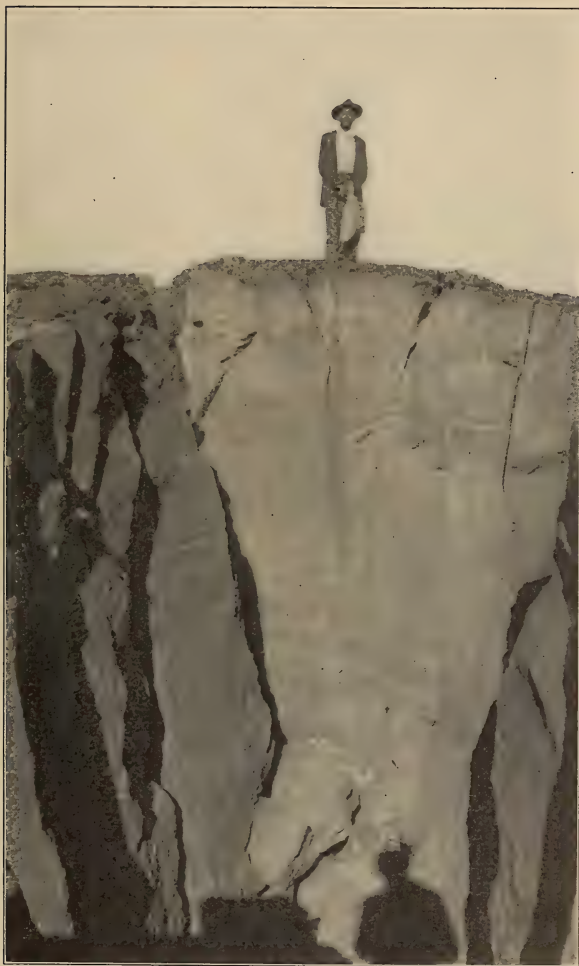


FIG. 4. Interior section of a "Schollendom."

formed Schollendoms invaded by fresh lava from below but, in such cases, the dome is deformed and its gracefully lenticular outline destroyed.

The general subject of *lava tunnels* must be left to a future paper and the same is to be said of those interesting tunnel products, the stalactites and stalagmites, the consideration of which would require much space and which are here mentioned as constituting a curious—if small and secondary—Kilauean formation. Notwithstanding all that has been written of these characteristic little forms, the main question, viz., their mode of formation, remains wholly unanswered; the various theories

FIG. 5.



FIG. 5. A tree mould of the projecting type.

being indefinite and inconclusive or else incompatible with the revealed characteristics of the product. The subject requires further study and the devoting to it of a separate paper.

Lava flows outside the great crater have, in some localities, produced the very interesting formations known as "Tree moulds." These are divergent in type according to the conditions of the flow of lava. If this has invested a forest of trees, or some great unit in the midst of a plain, and then, in great part, flowed away, a casing of lava—solidified by contact with the cold tree-trunk—will be left surrounding this to a height corresponding with the greatest depth attained by the stream at that point. This remains, therefore, as the *salient*, or *pro-*

jecting type of tree mould, standing above the surrounding plain as a monument to the original tree which, even if not at once destroyed by the igneous flood, has since suffered that decomposition and transmutation which is inevitable at the hand of time. (Fig. 5.)

In the *sunken* or *ground* type the lava has invaded low ground and has remained at virtually its full height around the stricken trees, of whose substance no vestige now remains

FIG. 6.



FIG. 6. Tree moulds of the sunken type.

but whose form, to the most minute detail, is preserved in lasting stone.

The visitor sees a number of cylindrical openings in the ground (lava) descending to the depth of the original flow which, in the cases observed by the writer, was from three to five meters. (Fig. 6.) It is most interesting to note that, at and near the surface, where the lava was not pressed with force against the tree and was also free to slightly shrink away upon cooling, the impression is of the grosser details only, such as the circular or elliptical form of the trunk with the more prominent corrugations while, the farther one descends, the more nearly perfect becomes the imprint of the bark. Near the bottom, where the lava pressed the tree with a force corresponding to the depth of the flow—and which we may

estimate as one kilogram per square centimeter—the impression is as reproduced in fig. 7, than which nothing more exquisitely precise can be imagined. It is a true “pressure casting,” so faithfully recording the finest detail that, from it, a naturalist may readily classify the original tree, of which the lava has thus formed so perfect a matrix.

The reader will marvel that the tree was not marred by its baptism of fire before such an impression could be obtained,

FIG. 7.



FIG. 7. Specimen from a tree mould.

but, if we except the resinous varieties, a growing tree-trunk, massive and full of moisture, will resist carbonization for a time sufficient to permit of the formation of a solidified layer or shell in contact with its surface and which—to make use of an expression almost hackneyed—is “a poor conductor of heat.” Something more than this, however, is required to account for the greater marvel that this mere shell is not then re-melted and destroyed by the flood of liquid lava at full temperature which continues to flow against it and the fact that it is not so re-fused can be explained, the writer believes, in but one way. Careful examination of the mould shows that not even the contact surface is vitreous and it is, therefore, obvious that the consolidation has taken place rather slowly, i. e., it

was not a matter of a very few seconds but of many minutes, as indeed we should infer, considering the backing of a mass of liquid at full heat. The result, then, is a shell of *crystalline rock*, deposited molecule by molecule after the manner of an electrotpe, and whose *fusion point is higher than the temperature of the liquid from which it consolidated*. We may believe, therefore, that there is no power in the flow to re-fuse the crystalline shell deposited therefrom as the lava—especially in the case of a *stream*—will not possess a sufficient degree of superheat to accomplish this; the shell, instead, will progressively increase in thickness.

The writer believes that failure to appreciate this most important fact, viz., that the fusion point of the crystalline rock is above the temperature at which the original lava will remain fluid, has frequently resulted in an exaggerated evaluation of the temperature of liquid lava through the practise of taking the melting point of the consolidated crystalline product as marking the lower limit of the liquid lava's temperature. The Halemaumau lake, for example, is liquid and active at 1050° C., but the rock of its consolidation—according to recent tests by Dr. E. S. Shepherd—melts at 1150° C.

It is the principle—truly universal in its distribution—of relaxation resulting in products which are then with difficulty removable. In the field of volcanism it is this which gives to the crater ledges their stability, to the floating island its span of existence, and which for a time ensures the growth and preservation—as it must eventually set the seal of closure and extinction—of and to no less a formation than the volcanic edifice itself.

Posillipo, Naples, May 6, 1913.

ART. XVIII.—*Marked Unconformity between Carboniferous and Devonian Strata in Upper Mississippi Valley*; by
CHARLES R. KEYES.

AFTER half a century's controversy the final adjudication of the Chemung problem in the Upper Mississippi region seems at hand. Exact determination of the stratigraphic horizon of a marked plane of unconformity which may be properly regarded as delimiting the base of the Carboniferous rocks of this province gives answer to a number of long standing questions.

In the delimitation and correlation of geologic terranes the superior value of diastrophic, or orogenic, criteria over all other lines of evidence has been recently urged by a number of writers,* notably Chamberlin† and Willis,‡ while orogenic criteria aided by fossils are urged by Suess,§ Schuchert,|| and Ulrich.¶ As is well known, the most striking expression of orogenic movement is the unconformable relations of strata.

Recently, during the progress of certain investigations for city water supplies in Iowa, Missouri, and Illinois, it became necessary to make some rather nice calculations on the thickness and extent of sundry geologic formations. In the course of this work a number of facts were disclosed bearing directly upon the vexed problems mentioned. There are given us for the first time definite data upon the actual stratigraphic relations existing between the rocks of the two distinct geologic ages.

The general geologic section of the Devonian-Carboniferous rocks of southeastern Iowa and northeastern Missouri is as follows:

<i>General Geologic Section.</i>		Feet
CARBONIFEROUS	{ Burlington limestone	---
	{ Chouteau limestone	10
	{ Hannibal shales	75
	{ Louisiana limestone	50
	{ Saverton (blue) shales**	50
	{ Grassy (black) shales	40
<i>Unconformity.</i>		
DEVONIAN	{ Lime Creek (blue) shales	125
	{ Cedar limestone	---

* American Geologist, vol. xviii, p. 289, 1896.

† Das Antlitz der Erde, vol. ii, p. 15, 1888.

‡ Journal of Geology, vol. xvii, p. 685, 1909.

§ Bull. Geol. Soc. America, vol. xx, p. 447, 1910.

|| Science, N. S., vol. xxxi, p. 243, 1910.

¶ Bull. Geol. Soc. America, vol. xxii, p. 394, 1911.

** This name is the local one usually applied to the blue shales lying between the Grassy black shales and the Louisiana limestone as well exposed at Saverton station, in Ralls county, Missouri. The formation probably attains a maximum thickness of at least 75 feet.

The stratigraphic relations of the several terranes are best shown in cross-section as they are plotted along the line of the Mississippi river from Louisiana, Missouri, to Muscatine, Iowa (fig. 1).

Detailed vertical sections I have given in another place.* At this time the shales lying at the base of the Louisiana limestone were little considered, since at the town of Louisiana they were only two feet thick and the northern localities were not yet carefully studied.† Comparisons of the Iowa and Missouri sections are made in the report on the geology of Des Moines county.‡ At one time§ it seemed that upon faunal grounds the Kinderhook shales as exposed at Louisiana could just as well be included in the Devonian section, but this old view long since gave way to the stratigraphic evidence.

The Chouteau limestone is quite thin on the Mississippi river, but rapidly becomes thicker to the westward. At Louisiana the Hannibal shales are 75 feet thick; at Keokuk, 65 feet; at Burlington about 50 feet of the blue shales in the base of the river-bluffs are assignable here. The Louisiana limestone, which is 50 feet thick at the type-locality, becomes gradually thinner northward, until at Keokuk it is only 10 feet in thickness, and soon vanishes altogether as shown by well-sections. This permits the overlying and underlying shales of Missouri to come together in Iowa and form one continuous shale-section.

Immediately beneath the Louisiana limestone at the original locality are two feet of blue shales. This apparently insignificant layer is usually included in the Grassy black shales below.¶ It now seems to have much greater importance. Northward

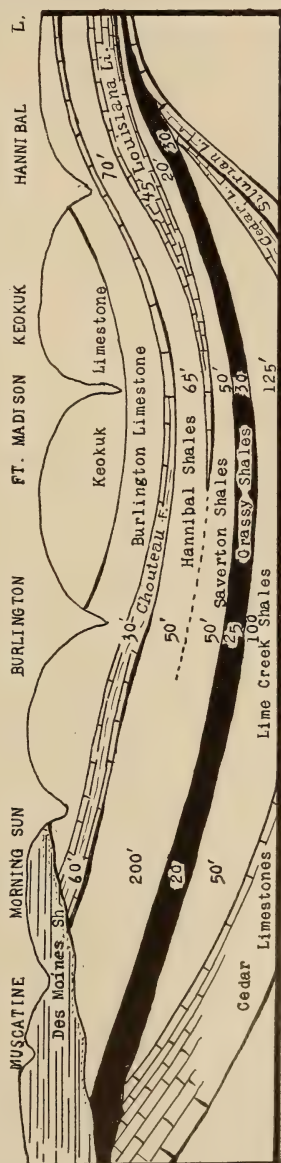


FIG. 1. Geologic cross-section along Mississippi River.

* Bull. Geol. Soc. America, vol. iii, p. 283, 1892.

† American Geologist, vol. x, p. 384, 1892.

‡ Iowa Geol. Surv., vol. iii, p. 436, 1894.

§ Trans. St. Louis Acad. Sci., vol. vii, p. 369, 1897.

¶ Proc. Iowa Acad. Sci., vol. v, p. 66, 1898.

from Louisiana these shales rapidly become thicker. At Hannibal they measure 20 feet in thickness; at Keokuk, probably not less than 50 feet; beyond, they merge with the Hannibal shales.

The Grassy black shales* are only four feet thick at Louisiana. They attain a greater vertical measurement northward. Before disappearing below river-level in the Keokuk syncline, they reach a thickness of 30 feet. In well-sections at Keokuk they have not been definitely recognized or separated from the associated shales. At Morning Sun, north of Burlington, they are distinctly present in a number of deep-well sections. They have been traced farther north to beyond Muscatine, where Udden† has given them the title of Sweetland beds. Here they are 45 feet thick; rest in notable unconformity upon the Cedar limestones; and have resting upon them unconformably the Des Moines coal measures.

Below the black shales there are still other blue shales. They are not exposed above river-level at either end of the syncline; but as shown in deep-well sections, at Keokuk, there are at least 125 feet referable to them; at Burlington, about 100 feet; and at Morning Sun, 50 feet. When the Iowa‡ and Missouri§ reports were printed it was surmised that this part of the great shale section at Burlington rested directly upon, or was an integral portion of the shales called farther north the Lime Creek formation. Since that time this view has proved to be really correct. The shales in question actually continue in full development to the Minnesota boundary. They rest on the Callaway limestone in Missouri, which appears to be the exact equivalent of the Cedar limestone in Iowa.

The Grassy shales are of exceptional interest since, in spite of their associated faunal affinities, they probably represent the basal member of the Carboniferous section of the Upper Mississippi region. At Louisiana these shales recline directly upon Silurian limestones. A few miles away they lie immediately upon the Callaway (Devonian) limestone. Farther on the Lime Creek shales are found immediately beneath. At their base, therefore, a marked unconformity exists, which is also well displayed at the north, above Muscatine.

The present correlation of the Grassy black shales seems to set at rest several moot questions. They, doubtless, represent the Chattanooga black shales which in the south constitute, according to Schuchert,|| the base of the Mississippian section. They are not to be regarded as Devonian in age, as suggested

* Proc. Iowa Acad. Sci., vol. v, p. 60, 1898.

† Iowa Geol. Surv., vol. ix, p. 289, 1899.

‡ Iowa Geol. Surv., vol. i, p. 55, 1893.

§ Missouri Geol. Surv., vol. iv, p. 56, 1894.

|| Bull. Geol. Soc. America, vol. xx, p. 548, 1910.

by Udden.* They are not a local development of uncertain affinities as stated by Calvin;† nor do they underlie the Lime Creek shales as indicated in his general geologic section of Iowa.‡ It appears that Owen and Norwood§ in drawing the line of separation of the Devonian and Carboniferous strata in the Mississippi valley at the black shale, displayed phenomenally keen insight into the real geologic succession in the region.

Particularly noteworthy the Burlington section remains. When discussing the Devonian Interval in Missouri|| I was inclined to regard the entire shale-section between the Cedar limestone and the Chouteau limestone as a distinct unit, Devonian in age, and having intercalated the lens of Louisiana limestone. This conclusion was based largely upon faunal grounds and especially upon the *Gomphoceras* fauna then newly found high up in the section at Burlington, and afterwards especially noted by Weller.¶ This fauna was discovered by me at the time that the report on Des Moines county was being printed,** and six years later the fossils were turned over by Dr. Calvin to Professor Weller for critical examination. As a result Weller was led to correlate†† the lithographic limestone (bed 4) of the Chouteau formation, at Burlington, with the Louisiana limestone at the typical locality, and to regard the fossils of the shales as constituting the oldest Kinderhook fauna.

Stratigraphically there seems to be no doubt whatever that Bed 4 at Burlington cannot possibly be the continuation of the Louisiana limestone. Yet there is really no serious faunal discrepancy in Weller's determinations. That the older fauna—a fauna of marked Devonian aspects—should occur at a stratigraphic horizon higher than that of the Louisiana limestone is not remarkable. It is easily explained. At Burlington the shale succession from the Grassy formation to the Chouteau limestone is uninterrupted; at Louisiana a thick limestone divides the shales. In the north the fauna of the Grassy black shales continued upward unbroken. The *Gomphoceras* fauna from the shales 40 feet below the Burlington limestone at Burlington is probably the characteristic fauna of the Hannibal shales, although the latter at the typical locality have thus far proved unfossiliferous.

* Iowa Geol. Surv., vol. ix, p. 301, 1899.

† Journal of Geology, vol. xiv, p. 572, 1906.

‡ Iowa Geol. Surv., vol. xvii, p. 192, 1907.

§ Researches on the Protozoic and Carboniferous Rocks of Central Kentucky during the year 1846, 1847.

|| Bull. Geol. Soc. America, vol. xiii, p. 267, 1902.

¶ Iowa Geol. Surv., vol. x, p. 69, 1900.

** Ibid., vol. iii, p. 433, 1895.

†† Ibid., vol. x, p. 70, 1900.

The blue shales below the Grassy shales and above the Cedar limestone show in deep-well sections a thickness of at least 125 feet. They are without doubt a continuation of the Lime Creek shales. Along the Mississippi river they become attenuated towards the northeast; and some little distance south of Muscatine and to the south of Hannibal they fail altogether. Fifty miles southwest of the last mentioned place, near Fulton, they appear to be fully represented by the 50 feet of Snyder shales which immediately overlie the Callaway limestone. From Burlington to the northwest they are recognizable as far as Marshall county and characteristic Lime Creek fossils have been taken from well-drillings in this district. From Marshall the belt swerves to the east somewhat, and in Floyd county the Kinderhook blue shales directly cover them.

In the delimitation of geologic formations I place far more weight on the stratigraphic evidence of a well-marked unconformity than on the occurrence of a fauna of Devonian aspects high up in the thick shale-succession. To me unconformity means more than any other classificatory or correlative criterion.*

* *American Geologist*, vol. xviii, p. 289, 1896.

ART. XIX.—*A Meteoric Iron from Paulding County, Georgia*; by THOMAS L. WATSON.

THE iron described below was obtained by the writer about twelve years ago from a party who reported having found it in the northern part of Paulding County, northwest Georgia. Neither the date of find nor the exact locality from which the iron came can be given, nor is anything known regarding its fall. Excepting the extreme northwest corner, all of Paulding County lies within the crystalline province of the state, but nothing is known of the natural conditions surrounding the find of the iron.

When secured by the writer the mass was deeply coated with a thickness of oxidation products, small fragments of which could be readily broken from the surface. Since being in the possession of the writer, it has been kept carefully wrapped in several thicknesses of paper in a tightly closed box at room temperature. During this time the mass has undergone rapid oxidation and much of it has crumbled into small and large fragments of yellow to reddish brown color, resembling much of the ordinary brown hematite (limonite). Naturally, the fragments are of irregular shapes and some exhibit a rudely shaly or platy structure.

The total weight of the mass (1912), including the fresh iron and the detached oxidized small and large fragments that had crumbled from it, was 725.1 grams. As separately weighed the two parts of the iron (unoxidized or fresh, and oxidized or altered) gave the following results:

	Grams
Fresh iron.....	134.3
Oxidized iron, including fragments of variable size and weight.....	590.8
	<hr/>
Total	725.1

Five of the largest fragments of the oxidized portion of the iron gave, when separately weighed, 110.4, 64.0, 52.8, 20.0, and 13.8 grams, respectively—a total weight of 261.0 grams. The remainder of the oxidized portion of the iron (329.8 grams) was composed of smaller fragments of irregular outline and a goodly amount of very fine material of almost dustlike particles. A fractured surface shows the mass to be somewhat porous and the cavities lined with deep red oxide of iron (hematite). Other pieces show much admixed deep red oxide with blue-black surfaces. Practically all of the oxidized material reacted strongly magnetic, most of the particles showing polarity.

The maximum diameters of the fresh portion of the iron are 6^{cm} by 3·7^{cm} by 2·2^{cm} (fig. 1); weight 134·3 grams. Its general outline is irregular and when examined in detail is quite ragged in places. The sawn and polished surface exhibits several minute fractures with oxidation apparent along most of these. In structure the iron is a coarse (broad) octahedrite, the lamellæ being mostly 1·5 to 2^{mm} in width (fig. 2).

FIG. 1.

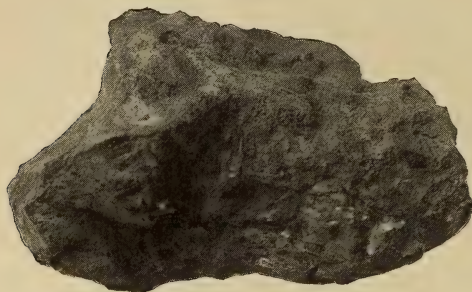
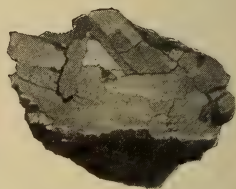


FIG. 2.



Through the courtesy of Doctor George P. Merrill, the writer was afforded opportunity for comparing the Paulding County iron with other irons from Georgia and the adjoining states in the collections of the U. S. National Museum. The results were uncertain and of slight value, because of the very small surface of the available Paulding County iron, but so far as could be judged it resembled more closely the Cherokee County (Canton), Georgia, iron, and the following two from Tennessee: Cleveland (East Tennessee) and Cooperstown, Robertson County. In neither case, however, was the resemblance close, but only very general, and so far as the comparison has value it must be concluded that the Paulding County iron is different from any yet found in Georgia and adjoining states in the collections of the U. S. National Museum.

It is of interest to note that of the three irons mentioned above, which most closely resemble the Paulding County iron, Farrington* groups the one from Georgia (Canton, Cherokee County) with "coarsest octahedrites" and the two from Tennessee (Cleveland and Cooperstown) with "medium octahedrites." The analysis of the Canton Georgia iron (coarsest octahedrite) is given in column II below for comparison, with that of the Paulding County iron. The two irons are quite similar in composition. Analyses of the Cleveland and

* Farrington, O. C.: Analyses of Iron Meteorites Compiled and Classified, Field Columbian Museum, Publication 120, Geological Series, 1907, vol. iii, No. 5, pp. 72-73, 78-79.

Cooperstown Tennessee irons show lower iron and higher nickel than the Paulding County, Georgia, iron, which alone is sufficient to distinguish them.

A separate chemical analysis was made of (a) the fresh iron and (b) the oxidized portion of the mass by Mr. Wm. M. Thornton, Jr., of Yale University. The results are given below. For purposes of comparison there is given in column II an analysis by Doctor H. N. Stokes* of the Canton octahedrite (coarsest) from Cherokee County, Georgia.

	I	II
	Per cent	Per cent
Iron (Fe).....	93·26	91·96
Nickel (Ni).....	6·34	6·70
Cobalt (Co).....	0·50	0·50
Copper (Cu).....	Trace	0·03
Phosphorus (P).....	0·23	0·11
Chlorine (Cl).....	0·01	---
Sulphur (S).....	None	0·01
Silicon (Si).....	None	Trace
Carbon (C).....	---	Trace ?
	-----	-----
	100·34	99·31
Specific gravity.....	7·886	

I. Paulding County, Georgia, fresh iron, Wm. M. Thornton, Jr., analyst.

II. Cherokee County (Canton), Georgia, iron, H. N. Stokes, analyst.

The analysis shows nothing unusual in the composition of the Paulding County iron. Because of the limited amount of the fresh iron available for analysis, no search was made for the rarer elements frequently reported in minute quantity in many octahedrites.†

In the preparation of the oxidized portion of the iron used for analysis, all coarse fragments were sorted out and discarded, no fragments or particles being broken or crushed. The remainder of the mass (143·8 grams) was thrown on a sieve of 20 meshes to the linear inch. Out of the 143·8 grams, 32 grams passed through which still contained small cores of metallic iron. It was therefore quartered and the portion thus obtained gently ground in an agate mortar and passed through silk bolting cloth of about 100 meshes to the linear inch. This process was repeated upon the residue until practically no powder passed through the sieve. The sifted portions, after being mixed together, made up the sample for chemical analysis.

* Howell, E. E., this Journal, vol. 1, p. 252, 1905.

† Merrill, Geo. P.: Minor Constituents of Meteorites, this Journal, vol. xxxv, pp. 509-525, 1913.

Of the 32 grams which passed through the 20-mesh sieve, 25.9 grams were strongly magnetic; the residue (6.1 grams) was essentially nonmagnetic. Of the 111.8 grams that did not pass the 20-mesh sieve, 109 grams were strongly magnetic, 2.8 grams being nonmagnetic or essentially so.

The analysis by Mr. Thornton of the above sample of the oxidized iron is as follows:

Analysis of oxidized portion of Paulding County, Georgia, iron.

(Wm. M. Thornton, Jr., analyst.)

	Per cent
Fe ₂ O ₃	36.12
FeO	41.26
NiO	6.57
CoO	0.48
CuO	Trace
SiO ₂	0.26
P ₂ O ₅	0.48
Cl	2.21
H ₂ O (at 110° C.)	2.77
H ₂ O (above 110° C.)	9.23
	<hr/>
	99.38

A most extraordinary feature of this analysis which the writer cannot explain is the very abnormally high chlorine content. So far as the writer has been able to ascertain from an examination of many hundreds of analyses of meteoric irons from all parts of the world, it is enormously excessive, being many times greater than for any published analysis. In light of this fact the analyst, Mr. Thornton, at the request of the writer, redetermined the chlorine in a second portion of the oxidized iron with the following result:

	Per cent
H ₂ O at 110° C.	3.34
Chlorine (Cl)	1.99

When these results are compared with the same constituents in the analysis above, it will be observed that a difference is shown, but on recalculating the two chlorine determinations to the same (moisture free) basis the figures are in fairly close agreement.

Concerning these results, Mr. Thornton in a recent personal communication to the writer says: "The material is hygroscopic and the moisture content very variable; . . . I think it improbable that my first determination of chlorine (see above) in the first drawn sample is too high."

Brooks Museum, University of Virginia.

ART. XX.—*Pyroxmangite, a New Member of the Pyroxene Group and its Alteration Product, Skemmatite*; by W. E. FORD and W. M. BRADLEY.

THE minerals to be described in this paper were found four and one-half miles east of Iva, Anderson county, South Carolina, by Mr. George Letchworth English, of Shelby, N. C., who kindly submitted them to the Mineralogical Laboratory of the Sheffield Scientific School for investigation.

On preliminary examination one of them proved to be essentially a silicate of manganese and ferrous iron with the general characteristics of a pyroxene. It was at first thought to be a schefferite, but further study proved it to be quite distinct from that species. It differs from schefferite in that it contains only a little lime, no magnesia, and much higher percentages of iron and manganese oxides. Further, the crystallographic and optical properties show that it is triclinic. As far as the analysis goes it might be a highly ferriferous rhodonite, for the analysis given below does not differ materially from that of a rhodonite from Vester Silfberg given by Weibull and quoted by Dana as analysis 9, page 380, of the System of Mineralogy. The crystallographic and optical characters of the two minerals do not, however, agree as shown below. The cleavage angle of pyroxmangite differs from that of rhodonite by about half a degree. The extinction directions of the two minerals differ by angles ranging from 10 to 13 degrees. The axial angle of pyroxmangite is small and its optical character is positive, while the axial angle of rhodonite varies between 72° and 76° and it is optically negative. Pyroxmangite differs markedly in its composition from that of babingtonite. The conclusion, therefore, is that it is a new member of the Pyroxene Group, belonging in the triclinic section.

It was found only in cleavable masses, no indication of crystal forms being observed. It is triclinic as proved by the character of its cleavages and its optical structure. It shows two cleavages, one of which is quite good while the other is rather poor. The difference in the quality of the two cleavages is very distinct. The average of a number of measurements gave the angle between the two cleavage planes as $91^{\circ} 50'$. A parting plane, occupying the position of the crystal face $b(010)$ was occasionally to be observed. The angle between this plane and the better cleavage was measured as $45^{\circ} 14'$, giving the angle between it and the poorer cleavage as $42^{\circ} 56'$.

The hardness is 5.5–6. The specific gravity was determined as 3.80. The luster is vitreous, inclining to resinous. Its color

by the drawing table method of Becke and was determined as approximately $2V = 30^\circ$. The above facts are shown graphically in fig. 1. It is to be understood that because of the lack of crystal faces the exact orientation of the cleavage pieces is impossible, and therefore the position of the extinction directions might be the reverse of that shown in the figure.

The mineral was intimately associated with a black iron-manganese oxide, a description of which will be found beyond. This oxide is evidently an alteration product. The material used for analysis was selected from the purest specimen. It was crushed and the fragments sifted to an uniform grain. By experimentation it was found that the pyroxmangite was not attacked by hydrochloric acid, even at boiling temperature, but that the black oxide was completely soluble under such conditions. Consequently the powdered material was boiled in dilute hydrochloric acid until the decanted acid showed no further test for iron. After such treatment the grains of pyroxmangite, when examined under a lens, appeared of an uniform character, showing bright and unetched surfaces.

The method of analysis was briefly as follows. Water was determined by the direct method of Penfield.* Silica was determined as usual. The sesquioxides were separated by the basic acetate precipitation, dissolved in nitric acid and reprecipitated by ammonium hydroxide. The filtrate from the basic acetate and that from the ammonium hydroxide precipitations were evaporated separately and any further precipitates collected. The manganese was precipitated in the combined filtrates by means of bromine water, dissolved by strong sulphur dioxide water and again precipitated by acid sodium phosphate. Calcium was precipitated as the oxalate in the filtrate from the first manganese precipitation. No magnesium was found. Total iron and alumina were determined as usual. Careful qualitative tests proved that the iron was all ferrous in valence. The results of the analyses by Bradley follow:

	I	II	Average Ratios		Subtract ratios equivalent to RO. Al_2O_3 . SiO_2 .
SiO_2	47.17	47.11	47.14	0.78	$-0.023 = 0.757 = 1.00$
MnO	20.72	20.55	20.63	0.29	$0.717 - 0.023 = 0.694 = 0.917$
FeO	28.30	28.38	28.34	0.394	
CaO	1.85	1.91	1.88	0.033	
Al_2O_3	2.50	2.26	2.38	0.023	-0.023
H_2O	0.37	0.29	0.33		
	100.91	100.50	100.70		

* This Journal, xlviii, 31, 1894.

The analysis yields molecular ratios that agree with the accepted type of a pyroxene formula. The small amount of water was disregarded. It was probably due to incipient alteration. The alumina was presumed to be present in the combination $\text{RO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$. After subtracting the proper amounts from the silica and protoxide ratios to satisfy this formula, the resulting ratios $\text{SiO}_2 : \text{RO}$ reduce to 1.00 : 0.917 which gives the metasilicate formula, RSiO_3 . The name *pyroxmangite* was given to the mineral in order to indicate that it is a *manganese pyroxene*.

As stated above, there was a black oxide of iron and manganese intimately associated with the pyroxmangite. The oxide

FIG. 2.



is unmistakably an alteration product. It surrounds the unaltered silicate, occurring on the outside of the specimens. The change from one substance to the other while confined to a small space is nevertheless gradual, there being no sharp dividing line between the two. In certain instances prominent cleavage and parting planes, which were evidently formed before the alteration took place, could be traced unbrokenly from one mineral into the other. Fig. 2 represents the change as shown in a thin section under the microscope. The alteration penetrates the pyroxmangite first along the cleavage cracks. The beginning of the alteration is shown in the section by a darkening of the color of the silicate to brown, which gradually intensifies until the substance becomes black and opaque.

This oxide is metallic in luster, giving a dark chocolate-brown streak. It is fusible about 4 to a black magnetic globule. Its hardness is between 5.5 and 6.0. When heated in the closed tube it yields abundant water and also gives off

oxygen gas. It gives manganese reactions with the fluxes. It is readily soluble in hydrochloric acid, giving off chlorine gas.

The method of analysis was as follows. The mineral was crushed and then dissolved in hydrochloric acid, the weight of the insoluble residue being deducted from that of the original portion. The sesquioxides were separated by the basic acetate precipitation and determined as usual. The manganese was determined as outlined above in the case of pyroxmangite. The available oxygen in the manganese oxide was determined by means of the oxalic acid method. The iron was proved to be all ferric in valence. The water was determined by the Penfield direct method.

The results of the analyses by Bradley follow :

	I	II	Average
MnO	31.71	31.96	31.84
O	6.50	6.56	6.53
Fe ₂ O ₃	43.67	44.24	43.95
Al ₂ O ₃	2.43	1.49	1.96
H ₂ O	15.57	15.55	15.56
	<hr/> 99.92	<hr/> 99.76	<hr/> 99.84

The ratio of the manganous oxide to the available oxygen is as 0.448 : 0.408 or as 1 : 0.910. This indicates that the oxide of manganese present must be almost wholly the dioxide, MnO₂. In the calculations to follow it has been assumed that the sum of the percentages of manganous oxide and available oxygen represent the percentage of manganese dioxide present. Considered in this way the analysis becomes as follows :

	Average	Ratios			Theoretical Composition
MnO ₂	38.36	0.441	or 1.48	or 3.00	37.88
Fe ₂ O ₃	43.95	0.298	1.00	2.00	46.44
Al ₂ O ₃	1.96				
H ₂ O	15.57	0.865	2.90	6.00	15.68
	<hr/> 99.83				<hr/> 100.00

From the ratios given above is derived the following formula, which closely expresses the composition of the mineral, 3MnO₂.2Fe₂O₃.6H₂O. The theoretical percentage composition corresponding to this formula is given in the last column above and agrees closely with the results of the analysis.

Although many oxides of manganese have been described, no one of them agrees with this mineral in its composition. Two new oxides of manganese from India, vredenburchite,

$3\text{Mn}_2\text{O}_4 \cdot 2\text{Fe}_2\text{O}_3$, and sitaparite, $9\text{Mn}_2\text{O}_3 \cdot 4\text{Fe}_2\text{O}_3 \cdot \text{MnO} \cdot 3\text{CaO}$, have been recently described by Fermor.* They contain ferric oxide in considerable amounts, but do not correspond in other respects to this mineral. Consequently, if this material is to be taken as a distinct species it must be considered as new. The grave question arises, shall a mineral which is so obviously an alteration product, and which shows no crystal form, be dignified by a species name? The close agreement of the analysis with the assumed formula is an argument in favor of its being a distinct species, but yet such an agreement might very well be accidental. Other analyses of material from the same locality, or better, of material from some other occurrence, would help to settle the problem. In order, however, that the above description and analysis be not overlooked in any future work on similar minerals, the name *skemmatite*, derived from the Greek, σκέμμα, a question, is proposed for the material.

Mineralogical Laboratory of the Sheffield Scientific School
of Yale University, New Haven, Conn.,
May 6th, 1913.

ART. XXI.—*New or little known Paleozoic Faunas from Wyoming and Idaho*; † by ELIOT BLACKWELDER.

WITHIN the past three years the writer has had occasion to collect fossils from many localities and horizons in the mountains of western Wyoming and a few in southern Idaho. Among these collections there are three or four which throw new light upon some questions of Rocky Mountain stratigraphy, and so it appears worth while to publish a brief account of them here in advance of the more detailed official reports, the preparation of which will require several years.

Ordovician graptolites from the Wood River valley, in southern Idaho.—The region about Hailey, on the northern border of the Snake River lava plain, has long been known as an important mining district. Geologists have studied the valley in more or less detail with special reference to the ore deposits, but they have found the sedimentary rocks almost entirely devoid of fossils. The few specimens thus far discovered appear to be of Carboniferous age.

* Mem. Geol. Survey, India, xxxvii, 1909.

† Published with the consent of the Director of the U. S. Geological Survey.

In June, 1912, the writer, while on a brief visit to this locality, was fortunate enough to find a zone of black slates which are crowded with well-preserved specimens of graptolites. Owing to the lack of time and facilities only a small collection was obtained, but in this material Mr. E. O. Ulrich has identified the following list of species :

- Didymograptus extensus* Hall.
- Didymograptus* cf. *nitidus* Hall.
- Didymograptus* cf. *planus* E. and W.
- Didymograptus* cf. *torquisti* Rued.
- Didymograptus caducens* (Salter) Rued.
- Didymograptus nanus* Lapw.
- Didymograptus bifidus* Hall.
- Tetragraptus similis* Hall.
- Dichograptus* cf. *octobrachiatus* Hall.
- Phyllograptus* n. sp. aff. *P. angustifolius* Hall.
- Lingula* sp. undet.
- Hexactinellid* sponge spicules.

Of this collection he says : " It probably represents an horizon intermediate between the *Tetragraptus* and the *Didymograptus bifidus* zones of the 'Canadian' as worked out by Dr. R. Ruedemann, in New York." This seems to prove that there are rocks of Lower Ordovician age in this part of Idaho. The fossils were found about a mile south of the pass on the Trail Creek road northeast of Ketchum. The detailed stratigraphy and the relations of the strata in which they were found still remain to be worked out.

Fossils from the Amsden formation in the Gros Ventre Range, Wyoming.—The series of soft sandstones, shales, and limestones which overlie the well-known Madison limestone, have been given the name Amsden formation by Darton.* It can be followed with more or less confidence clear across the state from the Black Hills to Idaho. Very few fossils have been found therein, and the majority even of those were poorly preserved or of doubtful significance. Some of them indicated Pennsylvanian age, while others were doubtfully referred to the Mississippi.

In 1911 fossils were found by the writer and C. W. Tomlinson at several horizons in the Amsden formation along the crest of the Gros Ventre Range, and were later submitted to Dr. G. H. Girty for study. Nearly all the specimens were found in a thin group of limestone beds a little below the middle of the formation. Dr. Girty has recognized two somewhat unlike faunules. The more widespread of the two consists almost entirely of brachiopods, with a few bryozoans,

* Darton, N. H., U. S. Geol. Survey, Prof. Paper 51, Geology of the Big Horn Mts., Wyoming ; and other papers.

echinoderms, etc. The other is an assemblage of mollusks, with a few brachiopods. The former occurs in the blackish to drab-gray limestones mentioned above, while the latter was found at the horizon about 60 feet lower in a dense, olive-gray limestone mottled with purple. It is thus evident that the environment of the two faunules in life was somewhat different. In the upper, or brachiopod faunule, the most characteristic species are *Productus cora*, *Composita subtilita*, and *Chonetes geinitzianus*. The lower or mollusk faunule is characterized especially by *Composita subtilita*, *Spirifer rockymontanus*, and a number of small gastropods and pelecypods. The full quota of species recognized in each zone is given below:

Fossils of the upper or brachiopod zone.

<i>Echinocrinus</i> sp.	✓ <i>Schizophoria</i> aff. <i>resupinoides</i> .
Crinoidal plates.	✓ <i>Chonetes Geinitzianus</i> .
<i>Batostomella</i> sp.	✓ <i>Chonetes granulifer</i> .
<i>Batostomella</i> ? sp.	✓ <i>Productus cora</i> .
<i>Rhombopora lepidodendroides</i> ?	✓ <i>Productus semireticulatus</i> .
<i>Stenopora</i> sp.	✓ <i>Productus nebraskensis</i> .
<i>Lingula umbonata</i> ?	✓ <i>Spirifer rockymontanus</i> .
<i>Lingula carbonaria</i> .	✓ <i>Composita subtilita</i> .
<i>Lingulidiscina</i> sp.	✓ <i>Conocardium</i> sp.
<i>Derbya robusta</i> .	Fish plate.

Fossils of the lower or mollusk zone.

Large crinoid stems.	✓ <i>Pleurophorus</i> 2 sp.
<i>Spirifer rockymontanus</i> ?	✓ <i>Bucanopsis</i> ? sp.
<i>Squamularia perplexa</i> ?	✓ <i>Euphemus</i> ? sp.
<i>Composita subtilita</i> ?	✓ <i>Pleurotomaria</i> sp.
<i>Myalina</i> sp.	✓ <i>Naticopsis</i> sp.
<i>Cypricardinia</i> sp.	✓ <i>Euomphalus</i> sp.

With reference to the age and correlation of these faunules, Dr. Girty says that the upper zone is "pretty clearly of Pennsylvanian age. They are also probably early Pennsylvanian." The lower faunule "evidently presents a different facies . . . The preservation of most of the species is poor and none of them are very diagnostic, but there is at least a possibility that this collection may prove to be of Upper Mississippian age." The remark may be added here, however, that both faunules occur in a single formation of distinctive and unified character, separated from the known lower Mississippian limestone by a distinct unconformity. Therefore, unless there is strong evidence to the contrary, it seems probable that both faunules belong to the same period.

Marine Permian (?) fossils from the Wind River Range.

From the Black Hills of South Dakota west to the eastern boundary of Idaho there are two prominent and relatively constant formations of late Paleozoic and early Mesozoic age. One of these, the Tensleep sandstone, is characteristically a massive, buff-colored sandstone which makes prominent cliffs, hogback ridges, and dip-slopes, wherever it appears. The upper terrane is the Chugwater formation, the brilliant color of which makes it the most easily recognized member of the entire sedimentary column. These two prominent terranes—the one apparently Pennsylvanian, the other usually referred to the Triassic—are separated almost invariably by 300–500 feet of shale, limestone, sandstone, and chert. This is the Embar formation of Darton.* At almost any of its outcrops, this formation may yield a few fossils, but most of those which have been collected are pelecypods, difficult to determine and of doubtful significance even when well preserved. This meager fauna has led paleontologists to refer the Embar to the Permian, the “Permo-Carboniferous,” or the Pennsylvanian, and always with a large element of doubt.

In 1877 Orestes St. John of the Hayden Survey found some richly fossiliferous beds in a formation which is evidently the same as the Embar, near Bull Lake on the northeast side of the Wind River Range. In his report,† he gave an admirable detailed section of the beds and referred to some of the fossils generically. Apparently the names were given as the result of rough field identifications, rather than after a critical study of collections in the laboratory. So far as I am able to learn no collections were brought home by St. John from this remarkable locality,—doubtless, because of the difficulty of transporting them more than 200 miles to the railroad,—and for many years no attention was paid to the find. Within the past decade, the same beds with similar fossils more or less well preserved have been visited by Darton and Woodruff along the north slope of the Wind River Range. Their published reports,‡ however, suggest that they made but small collections and obtained material some of which was not in a satisfactory state of preservation.

In 1910 a party in charge of the writer examined many of the canyons on the northeast slope of the Wind River Range in some detail, and there made careful stratigraphic sections and tolerably complete collections of fossils from many hori-

* Darton, N. H. *Op. cit.*

† U. S. Geog. and Geol. Survey of the Territories, F. V. Hayden in charge, 1878, vol. xii, part 1, pp. 242–248.

‡ Darton, N. H., *Paleozoic and Mesozoic of Central Wyoming*, Bull. Geol. Soc. Am., vol. xix, 1908, pp. 403–474.

Woodruff, E. G., *The Lander oil field*, U. S. Geol. Survey, Bull. 452 1911, pp. 12–14.

zons. Mr. J. M. Jessup was the indefatigable worker through whose efforts the bulk of the material was obtained. Some of the specimens were collected by Mr. C. L. Breger and the writer. The general report* on this trip, which has already been issued, contains a complete section of the Embar formation. It is the writer's expectation soon to publish in a bulletin of the U. S. Geological Survey a more detailed description of the stratigraphy of the north slope of the Wind River Range. This will include the Embar formation. Dr. G. H. Girty, of the U. S. Geological Survey, to whom the collections were submitted, reports over 60 species belonging to at least 45 genera. Although most of the fossils are brachiopods and pelecypods, there are also bryozoans, crinoids, scaphopods, gastropods, protozoans, and fishes.† The preliminary list of species identified in the 1910 collections from the lower half of the Embar formation follows:

Foraminifera (indet.)

Crinoids

Septopora ? sp.

Phyllopora n. sp.

Stenopora sp.

Rhombopora sp.

Fcnestella sp.

Lingula aff. *carbonaria*

Lingulidiscina Utahensis

Derbya sp.

Derbya n. sp.

Meekella sp.

Chonetes aff. *geinitzianus*

Productus nevadensis

Productus subhorridus

Productus cora

Productus multistriatus

Aulosteges n. sp.

Heterelasma ? n. sp.

Pugnax utah

Dielasma ? sp.

Dielasmina n. sp.

Spirifer aff. *cameratus*

Spirifer cameratus var.

Spiriferina pulchra

Spiriferina pulchra ?

Composita mexicana

Batostomella sp.

Batostomella n. sp.

Batostomella ? sp.

Lioclema n. sp.

Polypora sp.

Pseudomonotis aff. *hawni*

Pseudomonotis sp.

Myalina aff. *wyomingensis*

Myalina sp.

Euchondria neglecta

Solenomya sp.

Pteria sp.

Allerisma terminale ?

Allerisma n. sp.

Pleurophorus aff. *subcostatus*

Pleurophorus ? 3 sp.

Parallelodon sp.

Schizodus ? sp.

Astartella sp.

Leda obesa

Plagioglypta canna

Bellerophon aff. *crassus*

Bellerophon sp.

Bellerophon ? sp.

Patella n. sp.

Patella sp.

Euphemus subpapillosus

* Blackwelder, Eliot, Reconnaissance of the phosphate deposits in western Wyoming. U. S. Geol. Survey, Bull. 470-H, 1911, pp. 108-109.

† The fish fauna of the Embar has recently received notice from Mr. E. B. Branson, in a paper read at the Washington meeting of the Geological Society of America in December, 1911.

<i>Composita subtilita</i>	<i>Euphemus</i> ? sp.
<i>Hustedia meekana</i>	<i>Patellostium</i> ? sp.
<i>Acanthopecten coloradoensis</i>	<i>Pleurotomaria</i> sp.
<i>Aviculopecten coreyanus</i> ?	<i>Pseudomelania</i> ? sp.
<i>Aviculopecten</i> aff. <i>whitei</i>	<i>Enchostoma</i> sp.
<i>Aviculopecten</i> sp.	<i>Nautilus</i> ? sp.
<i>Pseudomonotis</i> n. sp.	Fish remains

Girty has already shown* that the Embar formation, as limited by Darton, contains two quite distinct faunas. Of these the hitherto better known is found in the upper half of the formation, and consists of large numbers of Lingulas and pelecypods, representing, however, only a few species, and even those seldom identifiable with confidence. The lower fauna, which is the subject of this note, may well be known as the *Spiriferina pulchra* fauna, after one of its most easily recognized and most widespread brachiopods. This fauna, in greatly impoverished state, occurs near Thermopolis and is known also from the Phosphoria formation of western Wyoming and southeastern Idaho.

Of this lower Embar fauna, Girty says, "the age of the *Spiriferina pulchra* fauna is probably Permian. This is suggested by such Permian types as *Phyllopora* and *Aulosteges*, together with the peculiar character of other species when compared with congeneric types in other western Pennsylvanian faunas."

There is little in common, however, between the *Spiriferina pulchra* fauna and that of the Guadaloupe group of Texas, or of the beds commonly referred to the Permian in Kansas. There are some things about it suggestive of the fossils which have been described from the *Productus* limestone of the Salt Range in India and from the *Schwagerina* limestone of the Ural Mountains in Russia. The former of these has generally been considered Permian and the latter upper Pennsylvanian. It is evident that the whole subject of correlation of the latest Paleozoic formations the world over is in a most unsatisfactory and unsettled state.

Madison, Wisc., March 25, 1913.

* See paper by Woodruff, noted above, p. 13.

ART. XXII. — *On Solid Solution in Minerals. IV. The Composition of Amorphous Minerals as Illustrated by Chrysocolla*; by H. W. FOOTE and W. M. BRADLEY.

AT the present time a definite chemical formula is ascribed to nearly every well-known mineral. The variations in composition which actually occur can in most cases be satisfactorily explained by assuming isomorphous replacement. Usually this consists in one or more metals being partly substituted for the metal in the ideal compound, or, what amounts to the same thing, a molecule of the ideal compound is substituted by a molecule of another similar in type. This common case occurs when potash replaces soda in albite. In rarer cases, compounds or radicals of different type appear to be isomorphous, or capable of forming solid solutions. For instance, in the plagioclases anorthite replaces albite, in nephelite there is a variable excess of silica,* and in pyrrhotite an excess of sulphur.†

The minerals which appear to present the greatest difficulty in the relation between actual composition and formula are those which commonly occur in the amorphous condition, but in these cases, as with well-crystallized minerals, definite formulæ are commonly given in all reference works on the subject. An examination of the facts will show, however, that in many amorphous minerals the actual composition found may differ very widely indeed from the theoretical value required by the formula.

As an illustration of this type of mineral, we have chosen chrysocolla, to which the formula $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$ is commonly assigned. We give below the ratios for $\text{SiO}_2 \cdot \text{CuO}$ and H_2O calculated for this mineral from the analyses given in Dana's *Mineralogy* and Hintze's *Handbuch*. The numbers are those given in the two reference books mentioned. We have omitted from Hintze's list the ratios of analyses as given by both Dana and Hintze.

In considering these ratios the fact must be taken into account that some of the analyses are undoubtedly inaccurate and the material used was impure. Too much weight, therefore, cannot be laid on the above results. Taking the results as they are, however, only nine of the thirty-one silica ratios show satisfactory values between 0.90 and 1.10. Six ratios are under .90 and sixteen above 1.10. Of the ratios for water, three only are between 1.80 and 2.20, eight are under 1.80 and twenty

* This Journal, xxxi, 25, 1911.

† Allen, Crenshaw and Johnson, *ibid.*, xxxiii, 169, 1912.

TABLE I.
Ratios calculated from Analyses of Chrysocolla.

Dana				Hintze			
No.	SiO ₂	CuO	H ₂ O	No.	SiO ₂	CuO	H ₂ O
1	1·20	1·00	2·23	4	2·60	1·00	3·40
2	1·05	"	1·86	5	·81	"	2·48
3	1·33	"	3·59	6	1·07	"	2·09
4	1·08	"	1·66	8	1·15	"	2·32
5	1·06	"	2·58	9	1·11	"	3·70
6	·71	"	1·47	10	1·03	"	2·95
7	2·68	"	5·06	11	1·01	"	2·16
8	1·35	"	4·21	14	1·23	"	1·65
9	1·89	"	4·40	22	1·88	"	3·91
10	2·13	"	2·62	23	·94	"	2·74
11	1·60	"	2·67	24	2·33	"	2·50
12	3·54	"	1·03	25	·39	"	1·23
13	1·62	"	·90	26	·18	"	·70
14	·97	"	2·24				
15	·33	"	·49				
16	·88	"	2·66				
17	1·07	"	3·63				
18	1·37	"	4·19				

are above 2·20. To put the results in another way, only 12 out of 62 ratios, or less than 20 per cent, are reasonably close to the theory for chrysocolla. So far, then, as the evidence goes which can be derived from the analyses given, there is little to support the formula $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$. On the other hand, there is just as little evidence in support of any other single formula.

To obtain further evidence, we have analyzed three specimens of chrysocolla. The main difficulty in determining the composition of chrysocolla is in obtaining pure material. By this we mean material which is *homogeneous*. For if different specimens of chrysocolla are each homogeneous and not mechanical mixtures, and show the essential characteristics of the mineral, we can see no reason why they must not all be regarded as this mineral even if the composition varies in the different specimens in a manner which is not of the character of ordinary isomorphous replacement. The samples of chrysocolla chosen for our work were picked from exceptionally fine large specimens. We were unable, however, to use heavy solutions for final purification. Potassium mercuric iodide solution, which was first tried, reacted with the mineral. Acetylene tetrabromide could apparently be used and a sample of the mineral was obtained by its means of specific gravity 2·336. We soon found, however, that this material had absorbed the tetrabromide in such a manner that it could not be removed by

washing with solvents. After such treatment, when heated in a closed tube, the mineral gave off not only its water, but also an oily liquid, presumably the tetrabromide or a decomposition product. We were therefore forced to abandon this method of purification. The fact that the tetrabromide is absorbed is interesting, however, as it suggests a comparison with some of the hydrogels like silicic acid, which also absorb various organic liquids. Our only means of purification, therefore, was by most careful picking. Small lumps of material which appeared pure, or nearly so, were broken up, sifted to uniform size, and separated under a magnifying glass. The material was afterward examined more carefully under a higher power microscope. Nos. 1 and 3 were almost perfectly pure and uniform in appearance. No. 2 was very slightly mottled in color. The method of analysis was as follows: The mineral was decomposed with hydrochloric acid and silica separated by two evaporations, as usual. It was tested for impurities by evaporation with hydrofluoric acid. In the filtrate from silica, copper was precipitated as sulphide and weighed as Cu_2S . The other bases were determined in the filtrate in the usual manner after removing hydrogen sulphide. Water was determined directly by Penfield's method.*

The results obtained are given in Table II.

TABLE II.

New Analyses of Chrysocolla (by Bradley).

	I			II		
	Locality, Arizona			Locality, Montana		
	1	2	Average	1	2	Average
SiO_2	38.16	38.12	38.14	50.32	50.57	50.45
CuO	36.71	36.77	36.74	37.77	38.12	37.94
H_2O	18.67	18.79	18.73	11.22	11.00	11.11
Al_2O_3	5.56	5.75	5.66	----	----	----
CaO} .....	.89	.91	.90	----	----	----
	99.99	100.34	100.17	99.31	99.69	99.50

III

Locality, Arizona

	1	2	Average
SiO_2	38.31	38.32	38.32
CuO	39.98	39.97	39.98
H_2O	19.88	19.86	19.87
Al_2O_3 .....	.91	1.04	.98
CaO} .....	.72	.84	.78
	99.80	100.03	99.92

* This Journal, lxviii, 30, 1894.

The ratios, calculated from the averages given above, are in Table III.

TABLE III.

Ratios of Analyses given in Table II.

	I	II	III
SiO ₂	1.36	1.75	1.26
CuO	1.00	1.00	1.00
H ₂ O	2.25	1.29	2.19
Al ₂ O ₃ .....	.12	----	.02
CaO .....	.04	----	.08

So far as leading to any definite formula is concerned, these ratios are just as unsatisfactory as those in the longer list previously given. If allowance be made for the alumina as allophane, the ratios are not improved. By assuming a mechanical mixture with a hydrated silica or opal of empirical composition, the residues in Nos. I and III could be forced to agree in composition with the formula usually assigned to chrysocolla, but this could not be done in No. II, where silica and water are both low.

It has seemed to the authors that the composition of this mineral, and probably of many other amorphous minerals, may, however, be regarded in a very simple manner by classifying them with the artificial hydrogels or gelatinous precipitates such as silicic acid or ferric hydroxide. It has been shown in numerous articles by Van Bemmelen and others, that these substances when freed from that part of the water which is present as a mechanical mixture, show values for vapor pressure which continually diminish as the substance is dehydrated. In other words, the vapor pressure of a hydrogel is a function of its composition. This leads to the conclusion that hydrogels are not mechanical mixtures of two definite hydrates, but the material is a homogeneous phase of variable composition, comparable in this respect to a solution of salt in water. If a hydrogel were a mechanical mixture of two definite hydrates, its vapor pressure at a given temperature would be constant, independent of its composition. This is the case, as is well known, with a mixture of two crystallized hydrates of a salt, the vapor pressure remaining constant as the mixture is dehydrated. These hydrogels, which appear to be homogeneous substances, have been called "adsorption compounds" by Van Bemmelen, but they may equally well be regarded as solid solutions of water in the oxide or in some lower hydrate.* The composition of these substances is not fixed, as in the case of a chemical compound, but is variable, depending on the conditions. The composition of an artificial silicic acid, for

* Jour. Amer. Chem. Soc., xxx, 1888, 1908.

instance, is not of necessity H_4SiO_4 or H_2SiO_3 , but homogeneous material containing more or less water may equally well be obtained, depending on the method of preparation.

Looked at in this way, the composition of chrysocolla is very simple. The mineral is not a chemical compound and no formula should be assigned, but a solid solution of copper oxide, silica and water as essential components, whose composition depends on the conditions of formation. This is, of course, not in accord with the view that every mineral is a definite chemical compound, but it accounts for the facts regarding composition, in a way that no definite formula can do. The possibility of there being chemical combination between the components of the solid solution is not excluded, just as a salt dissolved in water may be chemically combined with the latter, but we have no means, any more than with other types of solution, of determining the nature of this combination.

This tentative view of the composition of chrysocolla, if generally adopted, should logically be extended to a large number of the minerals which commonly occur in the amorphous condition. The fact that some of them occur occasionally in a more or less crystalline condition appears to be no objection to assuming solid solution. Poorly developed crystals are rather evidence of this. For instance, when ammonium chloride is pure, it is well crystallized. When it forms solid solutions with a variety of other chlorides of different types, such as nickel chloride, the crystals are distorted and imperfect.

A calculation of the ratios of 144 analyses of the various ferric hydrate minerals, given in Dana's *Mineralogy* and Hintze's *Handbuch*, indicates that with these minerals, as with chrysocolla, there are no definite compounds in the series, but that all may be considered as solid solutions of water either in ferric oxide or in some, as yet undetermined, lower hydrate.

Chemical and Mineralogical Laboratories
of the Sheffield Scientific School of Yale University,
New Haven, Conn., May, 1913.

SCIENTIFIC INTELLIGENCE.

I. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *A History of the first Half-Century of the National Academy of Sciences, 1863-1913.* Pp. xi, 399 ; with 8 portraits and 4 plates. Washington, 1913.—The Committee, with Dr. Arnold Hague, recording secretary of the National Academy, as chairman, which was charged four years ago with the preparation of the semi-centennial volume here noticed, is to be congratulated on the promptness with which its work has been completed, on the handsome form of the printed volume, on the careful and studious arrangement of its contents, and hence especially on the appointment of Mr. F. W. True, assistant secretary of the Smithsonian Institution, as author and editor. It is a good thing thus to place on record in concise and consecutive form an account of so dignified an organization as the National Academy of Sciences, regarding which many American scientists know so little.

The opening chapter (pp. 1-24), on the founding of the Academy, contains some interesting reminiscences about the preliminary discussions in which Secretary Henry, Superintendent Bache, Admiral Davis and Professors Louis Agassiz and Benjamin Pierce of Harvard appear to have been particularly active, and which led to the incorporation of the Academy by Act of Congress and its formal organization in the spring of 1863. As is often the case in such matters, no full account of the steps then taken has been preserved ; what is now presented has been industriously gleaned from various sources.

The second chapter (pp. 25-102) presents a running account of the peripatetic meetings in the autumn and of the Washington meetings in the spring, from which one may gather a good impression of the characteristic activities and interests of the assembled members, and of the subjects which have most attracted their attention ; but as is proper enough in a volume such as this, no indication is given of the greater attention shown by members in the business sessions for the election of new colleagues than in the scientific sessions for the presentation and discussion of learned papers. It was hoped that a list of the two thousand communications thus far presented might have been appended, but this was found impossible. One of the most important records concerns the growth of bequests and trust funds committed to the care of the Academy, chiefly for the support of scientific research, and now exceeding \$200,000 ; but the chief moral of this record is the surprising one that so distinguished a body of scientists should have been so seldom selected by generous testators as administrators of their scientific benefactions in a country as rich as ours.

Biographical sketches of the fifty incorporators of the Academy are given in the third chapter (pp. 103-200) with excellent portraits of the seven presidents, Bache, Henry, W. B. Rogers, Marsh, Gibbs, Agassiz and Remsen, who have served until this year; these sketches are for the most part condensed from the seven volumes of Biographical Memoirs, which constitute the most continuous and in that respect the most successful series of publications that the Academy has issued. Only eleven volumes of scientific Memoirs have been published, and periods varying from one to eighteen years have elapsed between the dates of imprint in the successive numbers; these eleven volumes contain only 68 titles, from which it is evident that the members of the Academy usually prefer to print their essays in some other medium than the Academic publications.

The Academy's work as scientific adviser to the Government is treated at length in the fourth chapter (pp. 201-334), from which it appears that, in the fifty years here considered, 32 reports have been requested by Congress or by governmental officials, and made by special committees of the Academy. The number of these reports in successive decades is 14, 2, 9, 4, 3. In view of the enormous increase in the scientific activity of the Government in the same fifty years, this showing is distinctly disappointing; indeed, in view of the indifference of Congress to the last two reports, the showing is so discouraging that the Academy might fairly ask to be excused from further trouble of this sort. A report on scientific exploration of the Philippine Islands, requested by President Roosevelt in 1902, was made in 1903, but did not reach Congress till 1905; it was then referred to a committee and ordered to be printed, "but was not reported back." In 1908 a report was asked for by Congress on "the methods and expenses of conducting scientific work under the government"; the report was carefully prepared by five academicians of high ability and eminent position, and submitted in January, 1909; but its recommendations "have not yet been adopted by Congress." The Act of Incorporation of the Academy provides that the actual expenses entailed in making these reports shall be paid; but that the members of the Academy "shall receive no compensation whatever for any services to the Government of the United States." This provision seems to be becoming more literally true than might have been anticipated when it was worded.

W. M. D.

2. *United States Geological Survey.*—A civil service examination for an editorial clerk (male) in the U. S. Geological Survey (salary \$1500 to \$1800) will be held on August 6, 7. The subjects embrace: English; French and German footnotes (translation into English); proof-reading and indexing; elementary Geology and Geological nomenclature. For further information apply to Geo. McLane Wood, U. S. G. S., Washington.

OBITUARY.

Professor EDUARD HOLZAPFEL, the well-known Professor of Geology in the University of Strassburg, died on June 11, 1913, at the age of 59 years.

WARD'S NATURAL SCIENCE ESTABLISHMENT

A Supply-House for Scientific Material.

Founded 1862.

Incorporated 1890.

DEPARTMENTS:

Geology, including Phenomenal and Physiographic.

Mineralogy, including also Rocks, Meteorites, etc.

Palaeontology. *Archaeology* and *Ethnology*.

Invertebrates, including Biology, Conchology, etc.

Zoology, including Osteology and Taxidermy.

Human Anatomy, including Craniology, Odontology, etc.

Models, Plaster Casts and Wall-Charts in all departments.

Circulars in any department free on request; address

Ward's Natural Science Establishment,

76-104 College Ave., Rochester, New York, U. S. A.

EIMER & AMEND

Complete Laboratory Furnishers

Chemical Apparatus, Balances, etc.

C. P. and T. P. Chemicals and Reagents

Platinum Ware, Best Hammered Blowpipe Outfits
and Assay Goods

**WE CARRY A LARGE STOCK OF
MINERALS FOR BLOWPIPE WORK,
ETC.**

EST'D - 1851
203-211-THIRD-AVE
NEW-YORK-CITY

CONTENTS.

	Page
ART. XI.—Velocities of Delta Rays ; by H. A. BUMSTEAD	91
XII.—Banded Gneisses of the Laurentian Highlands of Canada ; by M. E. WILSON	109
XIII.—Deep Wells at Findlay, Ohio ; by D. D. CONDIT ...	123
XIV.—Note on the Temperature in the Deep Boring at Findlay, Ohio ; by J. JOHNSTON	131
XV.—Arc Spectrum of Tellurium ; by H. S. UHLER and R. A. PATTERSON	135
XVI.—La Paz (Bolivia) Gorge ; by H. E. GREGORY	141
XVII.—Some Kilauean Formations ; by F. A. PERRET	151
XVIII.—Marked Unconformity between Carboniferous and Devonian Strata in Upper Mississippi Valley ; by C. R. KEYES	160
XIX.—Meteoric Iron from Paulding County, Georgia ; by T. L. WATSON	165
XX.—Pyroxmangite, a New Member of the Pyroxene Group and its Alteration Product, Skemmatite ; by W. E. FORD and W. M. BRADLEY	169
XXI.—New or little known Paleozoic Faunas from Wyo- ming and Idaho ; by E. BLACKWELDER	174
XXII.—Solid Solution in Minerals. IV. The Composition of Amorphous Minerals as illustrated by Chrysocolla ; by H. W. FOOTE and W. M. BRADLEY	180

SCIENTIFIC INTELLIGENCE.

Miscellaneous Scientific Intelligence—History of the first Half-Century of the National Academy of Sciences, 1863-1913, 185.—United States Geological Survey, 186.

Obituary—E. HOLZAPFEL, 186.

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE,
W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS,
LOUIS V. PIRSSON, HERBERT E. GREGORY
AND HORACE S. UHLER, OF NEW HAVEN,

PROFESSOR HENRY S. WILLIAMS, OF ITHACA,
PROFESSOR JOSEPH S. AMES, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

No. 213—SEPTEMBER, 1913.

WITH PLATE I.

NEW HAVEN, CONNECTICUT.

1913.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

NEW DISCOVERIES AND NEW FINDS.

BEAVERITE, A NEW MINERAL.

This mineral, which was fully described in the December, 1911, number of this Journal, I have been fortunate enough to secure the whole output of. It was found at the Horn Silver Mine in Utah and is a hydrous sulphate of copper, lead and ferric iron. It was found at a depth of 1600 feet. In appearance it resembles Carnotite. Prices 75¢ to \$2.00.

PSEUDOMORPHS OF LIMONITE AFTER MARCASITE.

These remarkable Pseudomorphs, which have never before been found in such clear cut specimens, was described and illustrated in the last number of this Journal. I have secured the majority of the finest of these specimens. They vary in size from 2 inches to 6 inches. In color they run from brown to glossy black and they have met with favor from all who have seen them. Prices from \$1.00 to \$10.00.

CHIASTOLITES.

Of these remarkable specimens, which are generally known as lucky stones, I have secured the finest lot ever found at Madera Co., California. They are cut and polished and sold singly and in collections from 25¢ to 50¢ for single specimens; 9 specimens all marked differently for \$5.00, and 18 specimens, all different markings, for \$18.00. Matrix specimens, polished on one side showing many crystals, from \$2.00 to \$8.00.

SYNTHETIC GEMS.

It is remarkable the interest that has been taken by scientists in these wonderful scientific discoveries. The Corundums are now produced in Pigeon blood, Blue, Yellow, Pink and White. Also the new Indestructible Pearls in strings with gold clasps. These are identical in hardness and rival in color and lustre the real gems. They can be dropped and stepped on without injury and are not affected by acids. My collection of the above is unrivalled, and prices of the same are remarkably low.

OTHER INTERESTING DISCOVERIES AND NEW FINDS

Will be found in our new Catalogues. These consist of a Mineral Catalogue of 28 pages; a Catalogue of California Minerals with fine Colored Plates; a Gem Catalogue of 12 pages, with illustrations, and other pamphlets and lists. These will be sent free of charge on application.

Do not delay in sending for these catalogues, which will enable you to secure minerals, gems, etc., at prices about one-half what they can be secured for elsewhere.

ALBERT H. PETEREIT

261 West 71st St.,

New York City.

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XXIII.—*Geologic Sketch of Titicaca Island and Adjoining Areas*; by HERBERT E. GREGORY.* With Plate I.

Introduction.

THE great Andean Plateau of southern Peru and northern Bolivia, the "altiplano," has a width in the Titicaca region of approximately 50 miles. Though possessing in itself relief exceeding a thousand feet, its plateau features are well brought out when the lofty ranges of the Cordillera Real and the Maritime Andes, between which it is hung, are taken into view. The bordering range on the northeast maintains a height of over 17,000 feet for a distance of 200 miles and reaches at Sorata (Illampu) a point 21,520 feet (Conway) above sea level. The western border of the plateau is a wide mountainous highland crossed by the railroad at 14,666 feet, and maintaining an average elevation in southern Peru of nearly 14,000 feet. As shown by Bowman, the Maritime Andes is a dissected peneplain and represents a mountain range which may have exceeded in height the present eastern Cordillera.

Occupying an irregular depression in the high plateau, between lat. $15^{\circ} 20'$ S. and $16^{\circ} 35'$ S. lies Lake Titicaca at an elevation of 12,500 feet above sea level. The lake is roughly rectangular in shape, one hundred miles long, and with an extreme breadth of thirty-eight miles.†

Its superficial area, calculated by planimeter from the best available maps, is approximately 4,000 square miles, and the length of the shoreline probably exceeds 500 miles.‡ Properly speaking, there are two lakes, connected by the rock-walled straits of Tiquina, five-eighths of a mile wide. The lower

* Geologist, Peruvian Expedition of 1912.

† The figures are from LeMaire. No complete instrumental survey of the lake has yet been undertaken.

‡ The figures given by Paz Soldan (270 miles) and by certain other writers are manifestly too small.

lake (Lago Pequeno) is shallow, with gently sloping bottom flats and large areas of low shore from which rise rock knobs and hogbacks of moderate height. The main lake (Lago Grande) reaches a depth of over nine hundred feet and is bordered by abruptly descending under-water shelves. Twenty-five tributaries, all small and greatly fluctuating in response to seasonal precipitation, supply the lake. Its surplus waters are carried by the Desaguadero into the salt Lake Poopó, thus forming a chain of fresh- and salt-water bodies like the Sea of Galilee-Jordan River-Dead Sea of Palestine and Utah Lake-Jordan River-Great Salt Lake of Utah. Thirty-six islands rise above the surface. The largest of these, Titicaca, has given its name to the lake, and as the Island of the Sun, shares with Koati (the Island of the Moon) and Tiahuanaco, a position as a center for archæological and historical research.

Physiography.

The Lake Floor.—The soundings made by LeMaire* and by Agassiz,† supplemented by scattered data, are sufficient for the construction of a bathymetric map of the basin now occupied by the waters of Titicaca. (See fig. 1, Plate I.)

It will be noted that Lago Pequeno is, properly speaking, not a part of the depression holding the waters of Titicaca. Its floor is remarkably flat, less than one-tenth of its area reaching a depth exceeding 20 feet; and a fall of ten feet in water level would expose about one-fifth of its bed, and effectively impede navigation. Lago Grande is seen to occupy a rectangular basin with abruptly ascending edges on three sides, and with a slope from southwest to northeast. The southeastern extremity partakes of the nature of a canyon,—Tiquina is a sharp-cut valley included between steeply sloping rock walls. The islands of Titicaca (fig. 2), Koati, and Soto are mountains, rising respectively 1,400, 1,500, and 1,300 feet above the basin floor, while the archipelago facing the coast at Escoma includes stacks and pinnacles, erosion remnants, rising above a slightly submerged platform. There are no indications that the tiny islands adjoining Titicaca Island form steps in a submerged causeway uniting Copacabana with the Bolivian mainland at Huaicho, as surmised by Bandelier, and no proof that the straits of Tiquina have been opened by faulting or torrent erosion since the lake attained its present dimensions, as is implied by various writers. How much of the shallowness of the bays of Puno, Rames and Achacache and of Lago Pequeno is due to waste furnished by

* Les Lacs des Hauts Plateaux de L'Amérique du sud, Paris, 1906.

† Hydrographic sketch of Lake Titicaca, Proc. Am. Acad. Arts and Sci., vol. xi, 1875-76.

the tributary streams, and how much to original depression, is impossible to determine, but it is significant that bays of great depths and precipitous shore fronts as Yampupata, Tiquina, Huaicho, Conina, and Huancane do not furnish an outlet for debris-laden streams of large size. Soundings so far available fail to indicate under-water channels or canyons whose orientation may be determined. That the basin, somewhat extended, is a warped, downfaulted area, is suggested by the

FIG. 2.

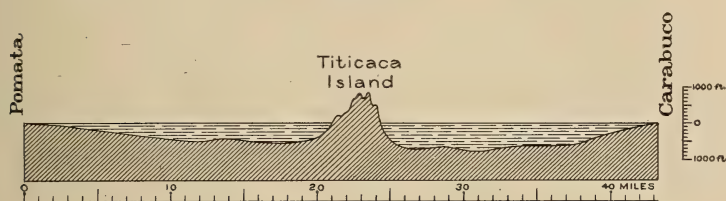


FIG. 2. Section across Lake Titicaca from Carabuco to Pomata showing mountainous character of Titicaca Island.

rectilinear quality of shore and island borders. It would appear also, from the character of the under-water slopes, that the topography had reached a stage of early maturity before the advent of structural movements which prepared the basin for filling by water.

The floor of the lake basin, in its deepest part and frequently near shore, was found by Agassiz* to be covered with "thick mud, the finest possible greenish black silt containing few fragments of shells—the mass being probably several feet thick." In a few localities sandy, shelly, and rocky bottom was found. The bed of Lago Pequeno appears to be covered with sand. Professor Thoulet analyzed three samples obtained by LeMaire, the first from Lago Pequeno near shore at Chillilaya, the second from a depth of 741 feet, the third from near shore at Huaicho on Lago Grande. The gray slime from Chillilaya contained microscopic fragments of siliceous spicules and diatoms, black, ferruginous, combustible specks (coal?), brick-colored particles, minute angular quartzes, black magnetic grains and sparsely distributed obsidian, pumice, hornblende, olivine, pyroxene, and mica. Percentage calculations of these samples gave: sand and plant fragments 13; calcareous slime 3; non-calcareous slime 13; calcareous mud 59; organic residue 12. Both entire and fragmentary shells were recovered. The sample from deep water gave in parts per 100: sand, etc. 3;

* Proc. Am. Acad., vol. xi, p. 284, 1875-76.

slime 78; calcareous mud, a trace; organic residue 18; indeterminate 2. This sample contained the same minerals as were found in Lago Pequeno and differs only in the absence of lime and greater abundance of globular diatoms. From the Huaicho dredging were obtained iron-coated grains of quartz "resembling the sands of Sahara," and a few volcanic fragments. Thoulet's studies show that the deeper parts of Titicaca are mantled with organic materials, chiefly diatoms, mingled with siliceous and calcareous (in Lago Pequeno) grains, minute fragments of minerals either wind-worn or volcanic, rarely meteoric. Near shore sand, plant fragments, and small shells occur.

As pointed out by Agassiz, the peculiar physical conditions of the lake bottom combined with high elevation and high temperature of water should tend to the specialization of genera,—a result which does not occur. The absence of unique forms and the poverty of species are remarkable. The two genera of fish and the mollusks belong to widely distributed fresh-water types. The Crustacea, however, have for their nearest relatives marine forms. An interesting fact pointed out by Orton is that one of the fishes, *Trichomycterus dispar*, occurs also in the Rimac and Guayaquil rivers.

Lake Water.—The temperature of the water, under the influence of the tropical sun and of the rarefied atmosphere, is remarkably uniform at all depths. Of thirty-four measurements made by Agassiz in which the temperature of the water at the bottom was compared with that at the surface and that of the air, the difference between bottom and surface was 3° – 4° ; the bottom temperature being 54° – 55° (one reading 51° at 618 feet), while the surface temperatures were 56° – 57° . Only one much larger range, 6.5° , was noted. At the same time (January 1st to March 5th) the temperature of the air ranged from 42° – 44° early morning to 55° – 63° during the hottest part of the day; extremes of 47° (cloudy) and 67° (very bright) were observed.

The mean of twenty-nine records taken by LeMaire from depths between 11 feet and 925 feet* give a value of 51.51° F., the highest reading being 52.52° F. at 79 feet and 607 feet, and the lowest 48.92° F. at 11 feet, 49.64° F. at 160 feet, and 49.46° F. at 740 feet. A grouping of LeMaire's thermometric observations indicates an increase from surface to 492 feet, reaching a maximum between 500 and 650 feet, followed by a slight decrease to the lowest depths. The temperatures of

* This is the greatest depth obtained by soundings. In Marie R. Wright's elaborate book "Bolivia" (1906) is an illustration of the loose statements frequently found in print; "Its depth varies from 250 feet to 1500 feet, and there are places where it is unfathomable" (p. 243).

the surface waters during July, during the time the above deep water temperatures were recorded, gives a mean of 52.06° F. The mean temperature of the air, including all hours of the day during the same period, was 45.32° F. It thus appears that the temperature of the surface water averages higher than that of the overlying air in summer as well as in winter. These records of water and air, though manifestly inadequate for meteorological discussion, are sufficient to show that freezing temperatures are rare, that ice forms only in narrow bays and then infrequently, and that accordingly the effect of frost in disintegrating rock either in contact with waves or with air is reduced to very low terms. Moreover the diurnal range of temperature is insufficient to aid greatly the disruption of rock masses, conditions which do not hold for the surrounding altiplano.

The water of the lake is fresh and palatable. Raimondi's analysis showed but a trace of saline matter and the analysis of three samples by Malliere gave 1.07 grams per liter of mineral content, of which .465 of a gram was chloride of sodium. The slightly disagreeable taste of samples taken near shore is due, according to Barranca, to the presence of magnesium and bicarbonate of lime formed by the action of carbonic acid liberated by the decomposition of *Myriophyllum* and *totora*, which flourish in the shallower bays. The water is clear, even in the rainy season when mud from streams discolors shore areas, and its transparency is little less than Geneva and Tahoe. The outflow of the lake (the Desaguadero, 45 meters wide, two to seven meters deep) is, according to Reck,* 4.822 cubic meters per minute. Evaporation amounts to five millimeters per day.†

Fluctuation in Level.—The dimensions of the present Titicaca are, as previously stated, one hundred miles by thirty-eight miles, with a superficial area of approximately 4000 square miles. That it formerly had a somewhat greater expanse seems to be sufficiently attested by historical and geological observations. Tovar‡ observes that cultivated fields now occupy small portions of exposed lake bottom at Guarisco, Acora, and Llave, that disputes regarding the ownership of reclaimed land at Capachica and Pusi are listed in local court records, and that in 1877 the waters of the lake reached the suburbs of Puno, now five "cuadras" (city blocks or squares) distant. The ancient ports of Huancavé, Moho, Conima, Ancoraimes, and Achachaci are now two to three kilometers

* Geog. Soc. de Lima, Tomo X.

† Prado, Bol. Soc. Geog. de Lima, Tomo I, 1892.

‡ Bol. Soc. Geog. de Lima, Tomo I, 1892.

inland. Agassiz states* that Lake Arapa and several lakes near the west shore are outliers of an ancient water body, and that the plain north of Lampa "only 100–150 feet above the lake . . . was one sheet of water." "The terraces of the former shores are still very distinctly seen." Tovar also records the tradition that Lake Umayo, now fifteen miles distant and fifty feet more or less above the Titicaca level, was formerly part of Titicaca and that the plains about the northwest end of the lake were formerly less extensive. Viscarra† states that within historical times the peninsula of Copacabana was an island. La Puente,‡ Zundt,§ Posnansky,|| Markham,¶ and Conway** accept the general view first stated by Orton,†† that the waters of the lake were vastly more extensive and surrounded Tiahuanaco within historical times.‡‡

When the Titicaca coast is examined it appears that the data presented by Tovar have little significance. Most of the places mentioned adjoin very shallow waters which are gradually being reclaimed by stream-borne sediments (fig. 3). This is particularly true of the areas mentioned by Agassiz, in which the Lampa and Rames are aggrading their beds and carrying sediment forward to form deltas. Squier appreciated this fact and remarks that "the region around the mouth of the Rames is a kind of delta, very low and level, interspersed with shallow pools as if but recently half rescued from the lake by deposits from the river." That the lake level has been eight to twelve feet higher than to-day is shown by the whitish band of deposited salts and discolored rock which decorates the bases of rock islands. While in part the evidence of the height reached by breakers, this horizontal band strongly suggests a former level below which the waters have sunk within probably a few decades. The annual fluctuation in lake level is approximately 4 feet, and so shallow is the bottom in places that hogs may feed several hundred feet from shore. In the absence of quantitative measurements and of definite locations of ancient shore lines, the conclusion of Tovar that the lake is "regularly diminishing" in a "surprising manner" is not justified.

* Proc. Am. Acad. Arts and Sci., vol. xi, 1875–76.

† Copacabana de los Incas, La Paz, 1901.

‡ Bol. Soc. Geog. de Lima, Tomo I, 1892.

§ Op. cit.

|| Bol. oficina Nacional de Estadística de Bolivia, 1911.

¶ Geog. Jour., October, 1910.

** Climbing and Explorations in the Bolivian Andes, 1901.

†† The Andes and the Amazon, 1876.

‡‡ In a paper presented by Professor Bowman before the Association of American Geographers, December, 1912, and later to be published, the rôle played by Lake Titicaca in the history of ancient Tiahuanaco is discussed in detail.

Berglund reports* that during twenty-three years' residence at Desaguadero the annual fluctuation reached five or six feet and that the level in 1906, following four years of deficient rainfall, was considerably lower than in 1909. Such variations are not uncommon in lakes of the world, even in humid regions

FIG. 3.



FIG. 3. Bay of Puno, showing a typical portion of the deltas extending into Lake Titicaca from the northwest.

marked by climatic regularity. A seasonal or cyclical change in climate, taken in connection with river-borne sediments, is sufficient to account for all authentic facts so far reported, without involving a hypothesis regarding the geological history

* Geog. Soc. de Lima, Tomo X.

of the lake. Until long-term, continuous records are available, it seems best to assume that Titicaca, in common with other water bodies, rises and falls in response to the increased and decreased precipitation which characterizes climatic cycles, the existence of which has been demonstrated for other parts of the world. The hypothesis of progressive diminution through centuries of time would accordingly be discarded.

Former Extent.—That Titicaca is the diminished representative of a vast interior sea which covered the altiplano in northern Bolivia and southern Peru, is claimed by nearly all students of this region. Thus, Agassiz states,* “Lake Titicaca itself must have, within a comparatively very recent geological period, formed quite an inland sea. The terraces of its former shores are everywhere most distinctly to be traced, showing that its water level must have had an elevation of 300 or 400 feet at least higher than its present level.” Le Maire† accepts Agassiz’s conclusions, supplemented by the existence of an ancient beach line in the Poopo basin, first observed by Musters,‡ and concludes that Titicaca and Poopo are parts of one interior sea covering the region between 15° and 21° south latitude, including La Paz and Oruro. The outlet was supposed to be through the present La Paz river into the Atlantic. “The largest lake in the world fed the largest river in the world.” “Within historical times the Desaguadero has been reduced from a wide strait to its present dimensions.” La Puente§ holds the same view but mentions no evidence bearing on this point. Posnansky|| believes that Titicaca is a remnant of an enormous salt sea separated from the ocean by uplift and drained through the eastern Cordilleras by a passage prepared by a cataclysmic rupture of its barrier. As if this were not sufficient proof of the power of the “titanic forces of nature,” Posnansky states that the region was again flooded by waters from Lagunillos freed by the rupture of massive rock walls,—a disaster which destroyed the civilization represented by Tiahuanaco! Zundt’s original views¶ were in harmony with those of Posnansky and required the elevation of strata to a height of 13,000 feet without destroying their horizontality. The steep faces of the mesas were considered the work of waves. Zundt’s later interpretation** is based on the hypothesis of a late Tertiary river, “Rio Titicaca,” which extended from Sicuani, Peru, to Illimani, Bolivia, via La Paz. This

* Proc. Am. Acad. Arts and Sci., vol. xi, 1875-76, p. 288.

† Lagos de Los Altiplanos, pp. 153-154. La Paz, 1909.

‡ Geog. Jour., xvi, 1871-77. § Op. cit., 1892.

|| Bol. oficina Nacional de Estadística de Bolivia, 64-66, La Paz, 1911, pp. 689-702.

¶ Appendix, D’Orbigny, 1907.

** Bol. Estadística, 67-69, 1911, and 70-72, 1912.

ancient channel was blocked by alluvium and glacial debris, thus isolating the present Titicaca. The ancient level of the original lake was not much above the present, and is marked on the rocks at the straits of Tiquina. Dueñas* expresses the view that ancient Titicaca may have extended into the Department of Cuzco. These views are only less extreme than the conclusion of Orton† that the "depression holding Lake Titicaca is apparently a volcanic basin; fragments of lava, porphyry, and jasper are scattered around and towers of igneous rock protrude through the sedimentary strata."

It will be noted that the conclusions of Le Maire, Posnansky, and others rest on the assumption that the hypothetical Titicaca had its outlet through the La Paz canyon, an assumption negatived by the fact that the deposits at La Paz are of later date than the lake basin, and the gorge itself is in large part post-glacial and recent. The existence of the hypothetical "Rio Titicaca" of Zundt, flowing in a wide valley or canyon sunk 1000 feet below the altiplano, is supported by no evidence from the lake bed, the altiplano, the valley of La Paz river, or from the upper part of the supposed valley now exposed to view in the region between Huancani and Sicuani. The enormous lake which is supposed to have occupied the basin between the two Andean ranges is believed by Posnansky to have been a detached portion of the sea elevated 12,000 to 13,000 feet without affecting the attitude of the Mesozoic strata. Points urged by Posnansky in favor of the marine origin of the basin are deposits of salt at several localities, deposits of sediments at La Paz and on the altiplano, and the marine affinities of the fauna of the lake. The first two points have little significance, since salt is a constituent of the country rock, and the sediments at La Paz are river deposits, not marine or even wholly lacustrine.‡

The lake fauna exhibits in part a marine facies, but is not necessarily of direct marine origin.§ The fish are fresh-water forms, with marine affinities; the mollusks, copepods, Daphnids, and ostracods are fresh-water forms; the amphipods present a marine aspect, but nothing definite may be said of their origin. The only true marine species mentioned by Posnansky, the *hippocampus*, is not found in the extensive collections of Agassiz and Le Maire. The presence of this species in the lake, a conclusion based on a specimen given to Posnansky by an Indian fisherman, and now in the private museum of the collector, requires further confirmation.

* Bol. Cuerpo de Ing. de Min., No. 53, Lima, 1907, p. 25.

† The Andes and the Amazon, 1876.

‡ See Gregory: The La Paz Gorge, this Journal, vol. xxxvi, pp. 141-150.

§ For data concerning the habitat of the Titicaca fauna, I am indebted to my colleague, Professor Petrunkevitch.

In this connection Agassiz's statement, quoted above, that "the terraces of its [Titicaca] former shore line are everywhere most distinctly to be traced," at "an elevation of 300 or 400 feet at least higher than its present level," deserves attention. Such high level terraces were not observed by the writer at Puno, Guaqui, Tiquina, Yampupata, or on Titicaca Island,—a fact which surprised me not a little, since I had assumed that such evidences of higher level were to be found on all sides. The shale, sandstone, and limestone, tilted at various angles and of different degrees of firmness, fretted by waves of considerable power, especially during the southern winter, would be expected to produce unmistakable rock benches, and the low-lying borders of parts of the lake offer favorable opportunities for beach-making. Moreover, the conditions for preserval of the shore forms in a semi-arid climate and where freezing is unusual are favorable. This does not prove, of course, that no such evidences of high-water level exist, for no detailed survey has as yet been made; but raised terraces are not "distinctly to be traced." In fact, no rock shelf or raised beach has been mapped or described, and there is no direct evidence of former high levels except for the relatively slight fluctuations discussed above. It is significant that La Puente, who stoutly affirms the former existence of a vast interior sea, made a traverse of the lake borders and visited many islands without recording the presence of ancient shore forms, and that Bowman in 1908 saw no signs of raised terraces.*

It will be noted that the argument against the presence of an ancient interior sea of vast dimensions rests chiefly on evidence of a negative value, and in the absence of topographic maps and of detailed physiographic studies must remain so. The problem involves the unraveling of the geologic history of the entire plateau region. From the data at hand it appears that the great interior depression, itself a plateau, owes its existence to faulting as implied by Bowman,† and that the downfaulted area was given its relative position after uplift and peneplanation of both the eastern and the Maritime Cordilleras in early Tertiary time. It is also probable that the floor of the sunken area was further modified by warping and selective faulting which produced a number of secondary depressions at considerable depths below the general floor. It is reasonable to suppose that such a downfaulted, warped surface would be occupied by a number of lakes, whose extent and permanency and degree of salinity would bear direct relations to the original topography, abundance of waste and climatic fluctuations.

* Private communication.

† This Journal, vol. xxviii, 1909.

Titicaca Island.—Titicaca Island is a representative of a large class of elevations including hogbacks, eroded folds, mesas, igneous masses, and probably fault blocks, which project above the general floor of the great interior basin or plateau. In common with its companions it has reached a mature stage of development and is, in brief, a residual prominence now partly submerged in the waters of a lake.

In outline Titicaca Island is very irregular (fig. 8). Five large bays set deeply into the land, in addition to ten or twelve other bays of one-fourth mile or less in width which scallop the island's border. Although the island has an area of 102 square miles, with an extreme length of only seven miles, and width nowhere exceeding three miles, the length of the coast line is 33 miles. Only at the southwest, where the sandstone ridge of Kakáyo-Kéna forms an unbroken wall for nearly five miles, does the coast assume a rectilinear quality.

The dominating feature of the island's surface is a backbone or central ridge, extending from Bilcokyma to Sicuyo, a distance of about seven miles, and following the direction of strike of the sedimentaries which compose it. On the northeast the Kea Kollu dome, extending far into the lake, assumes a commanding position, and on the southwest the long, straight ridge of Kakáyo-Kéna, culminating at Chullun-Kayani with an elevation of 800 feet, constitutes a conspicuous feature of the landscape. At the north the peninsula of Marcuni, tied to the land by the low isthmus of Challa, is a prominent feature when viewed from the lake. Approximately two-thirds of the island maintains a height of 400–500 feet, a few small areas are over 700 feet, and at Palla-Kasa a barometer reading of 13,330 feet, 830 feet above lake level, was obtained. This is probably the culminating point on the island, and Squier's figure, 2,000 feet, for the hills back of Challa is clearly an error. Back from the shore the surface has little sharp relief; cliffs and precipices and deeply cut chasms, except those formed by differential erosion of strata, are absent. Rounded ridges, flattened domes, flat saddles, and graded slopes form the surface, but not to the exclusion of minor steep rock slopes developed on the edges of tilted strata. In fact dip slopes and cuesta fronts in many places determine the topography and point to structural control of subordinate features. The valleys separating the rounded heights are broad V-shaped, frequently nearly flat, and the divides are everywhere inconspicuous. Only in their lower courses do the stream channels become steep-walled ditches and then only where wave-worn headlands have destroyed previously established grades. In short, the topography is mature or post-mature and youthful features are exceptional. (See figs. 4, 5 and 6.)

The coast shows everywhere signs of vigorous erosion ; headlands of bare rock, rising 100-300 feet above water, are numer-

FIG. 4.



FIG. 4. General view of the Peruvian shore of Lake Titicaca.

FIG. 5.



FIG. 5. Bay of Challa, Titicaca Island, showing beach and quality of hill slopes.

ous, and the short stretches of crescent beach are piled high with gravel. (Figs. 6 and 7.) The longer beaches, as at South Yumani and Challa, are built of fine materials with flat gradients and in more sheltered places luxuriant fields of reeds

FIG. 6.



FIG. 6. Kona Bay at South Yumani, showing beach, hill slope, and quality of the short drainage channels.

(*totoru*) are found. The Marcuni peninsula is tied to the land by a double-faced, wave-made beach. A traverse of the strand involves clambering over jutting rocks, climbing precipitous headlands, and walking on beaches of yielding sand. Most of the headlands plunge into deep water and the low sand beaches

which occupy sheltered coves slope gently lakeward for a few feet only to drop abruptly into the depths. The one hundred-foot bathymetric contour lies very close in-shore, except to the northwest, where the under-water platform forms a foundation for six islands, the largest only a little over a square mile in area, and all within two miles of Titicaca itself.

The agencies concerned in molding Titicaca are none of them vigorous except the waves, which are very efficient tools,

FIG. 7.



FIG. 7. Ahyjadero Bay, Titicaca Island, showing beach, lake cliff, and terraced fields (*andenes*). The strata exposed are limestones of Pennsylvanian age and mark the northwest side of the Ahyjadero fault. K. C. Heald, photo.

particularly during the southern summer. Chemical decomposition is favored by continuously moist atmosphere; stream erosion is checked by infrequency of rain and by flat gradients, which is offset only in part by the severity of sudden showers. The peeling of rocks occasioned by diurnal changes of temperature is little in evidence, owing to a nearly constant temperature which, influenced by the lake, maintains a mean of about 55° and very rarely drops below freezing. The waves, however, are vigorously attacking the shores and by selective erosion have developed dikes of sandstone by removing the less resistant shales, and here and there have surrounded masses which stand as stacks and skerries.

Structure.

The meager and disconnected geological mapping resulting from studies of Titicaca is an insufficient basis for the discussion of structural detail, and has allowed the perpetuation of such notions as that the basin is igneous in origin and that "smoldering fires still keep the waters warm;" that the Straits of Tiquina resulted from a volcanic eruption; that the coal is Tertiary; that the succession of strata and the age of the rocks are identical with those represented in the Alps, etc. The investigations of Forbes and D'Orbigny are, however, sufficient to indicate that the strata, Devonian and Carboniferous in age, have been thrown into folds, the truncated edges of whose limbs are responsible for the innumerable rounded hogbacks which form such conspicuous features of the landscape.

The basin of Lago Grande has the appearance of a "graben" — one or more down-sunken fault blocks bordered in places by escarpments, elsewhere by areas of steep faulting.

Faults are present in large numbers, but their length and amount of displacement and structural control are as yet unknown. In a section extending from Achacachi to La Guardia, entirely across the lake basin, Forbes encountered volcanics and highly contorted Devonian (D'Orbigny) strata, presumably cut off from overlying strata by a fault, the Carboniferous dipping westward until the Straits of Tiquina are reached, then dipping eastward across Copacabana. The straits are described as the locus of a fault, a "broken arch." Agassiz believed the Carboniferous to consist of a series of rather limited elongated basins with axes (determined by Forbes) running northwest-southeast. "By a series of such faults [as at Tiquina], more or less prominent, the successive basins of Carboniferous . . . have been separated."*

Structurally, Titicaca Island is a continuation of Copacabana peninsula. The strata are alike in composition, exhibit the same folds and nearly identical strikes and dips. This connection is well shown by a narrow sandstone hogback which projects as a cape from Copacabana and terminates in a line of islands, progressively decreasing in size. On Titicaca Island, the same bed apparently is included in the strata carried northwest along the line of strike. With the exception of the rounded knobs and eastward-facing cliffs carved by waves from the limestone, the whole surface of the island is formed of more or less modified hogbacks facing southwest and exhibiting the influence of structure. From a structural standpoint the island may be considered as a group of eroded, folded strata, drowned by the waters of the lake. The northwest-

* Agassiz, p. 283.

southeast trend of the ridges is characteristic. At Challa the strike is N. 60° ; at Ahyjadero (Pucára) the strike is N. 55° – 60° W.; and measures between N. 40° W. and N. 60° W. were taken at several localities. For Yampupata the figures are the same. Near South Yumani where the strata are faulted, N. 25° W. and N. 20° W. were measured, and at a few places, as on the ridge of Kuru-pata where a strike of N. 20° W. becomes in half a mile N. 40° E., the presence of minor horizontal and vertical folding is demonstrated. In addition to the faults traced by K. C. Heald and the writer and indicated on the map (fig. 8), there are many minor dislocations which are of economic importance, but only one so far observed has interrupted the stratigraphic succession to any considerable degree. The Ahyjadero-Kona fault has offset the strata for nearly one-half mile.

Economic.

The presence of coal at Yampupata and on Titicaca Island is mentioned by Forbes (1861) but was doubtless recognized at a much earlier date, since the absence of fuel other than llama dung for domestic purposes, as well as for smelting and for making steam, encouraged a search for mineral fuels. Agassiz (1875) found the mine at Yampupata producing "30 tons of coal per day," "of fair quality." More recent studies of these deposits were made by engineers in the employ of the Peruvian corporation and by Dereims, who reported a narrow band of coal running the length of the island.

The principal coal-bearing shales and sandstones traverse the island from South Yumani to Taana Bay as a belt ten to fifty feet in width, a limited proportion of which is of commercial value. The coal occurs in lenses and overlapping layers interleaved with argillaceous and sandy shales. Bands of true coal from a few inches to more than two feet in thickness were observed at South Yumani and northwest of Challa. The conditions of original deposition as well as field observation indicate that the maximum thickness of a given stratum of true coal will probably not exceed three feet and that such beds will vary greatly in linear extent. It is improbable that workable beds over three feet in thickness, continuous for more than 300 or 400 feet, will be found on the island. In several places examined, the coal lenses have much smaller dimensions.

Three exposures bordering South Yumani Bay show respectively: (1) 14 feet of carbonaceous shale with abundant thin streaks of impure coal of no value. (2) At a prospect hole, 10 feet more or less of carbonaceous shale contains beds of coal three inches to three feet thick, exceedingly variable in

thickness, extent and quality. One two-foot coal bed is fully half shale. The coal-bearing beds are overlaid by 6 feet of cross-bedded sandstone and underlaid by 30 feet of shale with lenses of sandstone. (3) Between South Yumani and Bilcokyma the section from bottom upwards is:

1. Shale with $\frac{1}{2}$ " to 1' lenses of coal.....	15 feet
2. Sandstone	4 "
3. Shale	2 "
4. Sandstone	3 "
5. Carbonaceous shale with $\frac{1}{4}$ "-2" beds of coal	5 "
6. Sandstone containing scattering fragments of coal	30 "

At Challa (Kcasa claim) the group of coal beds about 12 feet in thickness are approximately one-third "bone" and the thickest band of workable coal is probably less than two feet.

The section examined on the Taana claim shows at bottom thin-bedded sandstones and shales followed upward by

1. Carbonaceous shale, about half of which is coal in wavy, impure lenses	4-6 feet
2. Shales and sandstone	20 "
3. White sandstone	60 "
4. Shales and sandstone with $\frac{1}{2}$ "-1" layers of coal	20 "
5. White sandstone	10 "

In quality the coal is not very satisfactory, pyrite is abundant, and "high ash" is reported by the engineers of the Titicaca steamers, but the tests made by the Bolivian Rubber Company appear to have been fairly satisfactory. Mining on the island will necessarily be expensive owing to high dip of strata, irregular distribution of coal, the presence of water, and the distant source of supplies.

Stratigraphy.

Our knowledge of the stratigraphy of the Titicaca region is based primarily on the work of D'Orbigny,* Forbes,† and

* Voyage dans L'Amerique Meridionale, tomo iii, pt. 3, Paris, 1842. This volume, based on field studies during the years 1826-33, includes nine large hand-colored maps and sections and twenty-two lithographic plates of fossils. The government of Bolivia has made an important part of this rare work accessible by the publication of a Spanish edition (*Estudios sobre la Geologica de Bolivia*, translated and annotated by Victor E. Marchant La Paz, 1907).

† Report on the Geology of South America by David Forbes, with notes on fossils by Huxley, J. W. Salter, and T. Rupert Jones. Part 1, Bolivia and southern Peru. Quar. Jour. Geol. Soc., vol. xviii, 1861. A Spanish translation by Edmundo Sologuren was issued by the Sociedad Geographica de La Paz, 1901. The Carboniferous as delineated by Forbes manifestly occupies too small an area.

Agassiz.* Steinmann,† and especially Dereims,‡ have by their recent studies extended and somewhat modified the conclusions reached by earlier explorers. The publication by the Bolivian Ministerio de Justicia y Industria, La Paz, 1912, of a Mapa Geológico de Bolivia by Leonardo Olmos, serves as a basis for further field studies.§

This map so far as the Titicaca region is concerned is essentially a reproduction of D'Orbigny's Plate VIII, which exhibits Paleozoic formations as bands with prevailing northwest-southeast extensions. The periods represented west of the Cordillera Real are in succession: Silurian, forming the base of the range; Devonian, in a broad belt forming the eastern shore of Lago Pequeno, as well as the peninsula of Taraco; Carboniferous, forming the west shore and part of the south shore of Lago Pequeno, the peninsulas of Achacachi and Copacabana, and all the islands. No Cambrian has been reported from southern Peru or northern Bolivia. The presence of Silurian rests on ten species collected by D'Orbigny, none of which are accepted by Salter as properly determined; five Lower (?) Silurian and fourteen Upper Silurian species, mostly from the Cordillera Real, collected by Forbes and described by Salter; Ordovician graptolites described by Steinmann (1904); Steinmann's collection from southern Bolivia described by Ulrich,|| and on a collection of graptolites from Santa Domingo presented to the writer by Mr. Collins, manager of the Inca Mining Co. Dereims also reports Silurian at several localities south of Lake Titicaca. The presence of Devonian in the Titicaca region was first demonstrated by the discovery of seven species by D'Orbigny, four of which are accepted by Salter as characteristic of that era. These species, including three additional ones collected by Forbes, are unlike forms found elsewhere. Dereims found Devonian fossils in brown sandstone and shales near Lake Titicaca, a collection which as yet has not been reported upon.

Carboniferous strata were encountered by D'Orbigny on the shores and islands of Lago Pequeno, where brown sandstone is underlain by compact bluish gray "mountain limestone." The fossils collected from Amasa and Quebaya islands and from Yarbichambi comprise twenty-five species, all specifically unlike European forms, but resembling, according

* Agassiz and Garman, *Exploration of Lake Titicaca*, Bull. Mus. Comp. Zool., Harv. Coll., vol. iii, 1871-76, fossils described by Derby.

† A Sketch of the Geology of South America, *Am. Naturalist*, 1891, pp. 855-860.

‡ Excursiones Científicas 1901-04. Anexo de la Memoria de Gobierno y Fomento. La Paz, 1906.

§ One of the cross sections accompanying this map is confusing, in that the relations between Devonian and Carboniferous in the Copacabana area are not in harmony with the surface geology.

|| *Paleozoische Versteinerungen aus Bolivia*, Neues Jahrbuch, 1892.

to D'Orbigny, the fauna of Boulonais de Vise (Belgium). Salter lists thirteen species from the Carboniferous of Copacabana, many of which are identical with known European forms. The Carboniferous fossils from Yampupata collected by Agassiz and described by Derby include nine species; viz.: *Spirifera camerata*, *Athyris subtilita*, *Chonetes glabra*, *Productus costatus* (?), *Productus chandlessii*, *Productus cora*,

FIG. 8.

GEOLOGICAL MAP OF TITICACA ISLAND

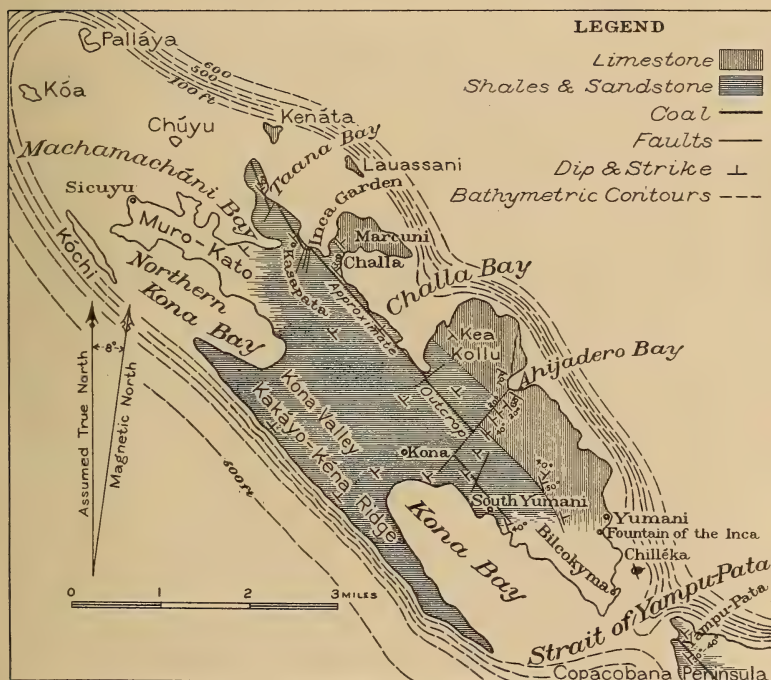


FIG. 8. Geologic sketch map of Titicaca Island based on observations by K. C. Heald and the writer. The base map is essentially that of Bandelier. The magnetic declination is assumed to be 8°.

Euomphalus antiquus, *Tropidoleptus carinatus* and *Vitulina pustulosa*; all but one of which “are represented in the coal measures of North America and Brazil by identical or closely related species.”* Dereims describes Carboniferous strata from the Titicaca region including Copacabana. The fossils

* Bull. Mus. Comp. Zool., vol. iii, p. 282, 1871-76.

from Titicaca Island collected by K. C. Heald and the writer in 1912 are, according to Schuchert,* of characteristic Pennsylvanian aspect.

The Permian, Triassic, Jurassic, Cretaceous, and Tertiary from the Titicaca area have as yet not been satisfactorily differentiated. Forbes assigned certain strata to the Permian on the ground of lithologic resemblance to the Russian Permian. D'Orbigny mapped Triassic which Dereims considers Permo-Carboniferous. The fossil *Chemnitzia potosensis*, relied upon by both these writers, seems not to be of sufficiently diagnostic

FIG. 9.



FIG. 9. Approximate geologic section from Kea-Kollu to South Yumani to illustrate section A, below.

value. The Puca sandstone at Cora-cora which extends northward into Peru,† and which is believed by Steinmann (1906) to be Cretaceous, is assigned by Dereims to the Permian or Permo-Carboniferous. Fresh-water Tertiary may be present in certain lake deposits of the Andean basin. Pleistocene deposits of considerable thickness are represented, but the glaciers appear not to have extended to the borders of the lake.

Through the courtesy of the Peruvian Corporation, the writer was enabled to make a brief examination of the stratigraphy of Titicaca Island, and of the northern extremity of Copacabana peninsula. The strata here are entirely sedimentary and of Carboniferous (Pennsylvanian) age. (See fig. 8.) The following sections indicate the relations of the various beds. Sections A, C, and D were measured by the writer. Sections B and E were compiled from data obtained by Mr. K. C. Heald. All measures recorded are approximate, especially for the thickest beds.

SECTION A.

Ahyjadero Bay (Pucara) to South Yumani. (Fig. 9.)

Distances determined by pacing, elevations estimated or measured by hand level.

* This collection, now in the Yale University Museum, will be discussed by Professor Schuchert at a later date.

† Adams, G. I., Ann. Report of the Smithsonian Institution for 1908, p. 404.

Feet

1. Limestone ; dense, blue-gray, fossiliferous, in beds 2'-6' thick ; numerous fractures with slight displacement. Strike N. 60° W., dip S.W. 340
2. Covered ; probable locus of north-south fault zone
3. Limestone ; massive, blue-gray ; in beds 2'-6' thick ; separated by $\frac{1}{2}$ "-3" beds of calcareous sandstone ; weathers like ornamental moulding ; abundantly fossiliferous. Strike N. 60° W., dip S.W. \angle 20° 250
4. Like Number 3. Dip S.E. \angle 10°-20° 200
5. Sandstone ; brown with yellow and green tones ; calcareous ; in beds 6"-3' 100
6. Limestone ; blue and purple ; with flat pancakes and cylindrical concretions of arenaceous material ; dip E. \angle 20° 50
7. Limestone and shaly sandstone, interbedded ; fossiliferous. Dip E. \angle 40° 150
8. Limestone ; gray ; calcareous sandstone ; yellow-gray, calcareous shales ; in beds 3"-1' thick ; forms wide bench. Dip E. \angle 50° 200
9. Sandstone, in beds 4'-10' ; medium- to fine-grained, loosely cemented, quartz grains, some black grains, gray with greenish and yellowish tones ; slightly cross-bedded ; one layer of dark red shale included 70
10. Shale ; dark red ; argillaceous and arenaceous ; includes 10" band of gray sandstone ; rare fossils 25
11. Sandstone ; coarse, cross-bedded ; brown, gray, green ; with lenses of shale 4
12. Shale ; red, drab, green ; lenses and thin bands of fine sandstone and 2' bed of coarse, cross-bedded sandstone. 30
13. Sandstone ; gray ; coarse, cross-bedded ; made up of overlapping sandstone lenses (1"-3") with plant fragments 6
14. Shale ; argillaceous, arenaceous and carbonaceous ; and yellow sandstone in thin beds including $\frac{1}{2}$ "-2" beds and lenses of coal 14
15. Shale ; argillaceous ; dark red and drab ; with lenses of red-brown sandstone 30
16. Sandstone ; brown, coarse, with red chert pebbles. 5
17. Partly covered. Shales, shaly sandstone, and sandstone in thin beds, becoming increasingly arenaceous with depth. A few thin calcareous shale beds included. Dip E. \angle 55° 160
18. Sandstone ; white, coarse, even-grained quartz ; cross-bedded ; massive and composed of overlapping lenses. At base are two lenses of excessively fine-grained, white, micaceous, paper-thin shales. Dip E. \angle 50° 200
19. Sandstone ; white quartz, cross-bedded 10
20. Shale ; arenaceous, paper-thin, white ; with plant impressions, and 3"-4" lenses of concretionary sandstone ; with limonite 6

	Feet
21. Shale ; arenaceous, argillaceous, and carbonaceous ; with abundant plant impressions and lenses of impure coal...	15
22. Sandstone ; white and arenaceous ; drab shale in beds 2"-1'	40
23. Sandstone ; white, cross-bedded, as No. 18	40
24. Sandstone ; brown ; in beds 2'-4', with thin brown and drab shale partings	30
25. Sandstone ; brown and gray ; in beds 3'-15', with argillaceous, arenaceous, and carbonaceous shales, exhibiting ripple marks, sun-cracks, and worm prints	200
26. Sandstone ; in three beds (30', 10', 10') with white and gray shale partings	50
27. Sandstone ; gray and yellow ; in thin beds with black and drab shales, constituting about $\frac{1}{4}$ of the material...	75

SECTION B.

Southeast end of Titicaca Island from summit of ridge to Kona Bay.

Measured by K. C. Heald.

General strike N. 25° W.

	Feet
1. Thin layer of ash (?).	
2. Limestone ; blue-gray ; fossiliferous ; massive. Dip, N. 20° E.	515
3. Talus-covered, but mostly thin-bedded limestone ; fossiliferous ; two bands of shale	200
4. Limestone ; thin-bedded ; hard	75
5. Sandstone ; medium-grained ; pebbles, red and white ; matrix, and general color, green ; soft, thin-bedded, cross-bedded in places ; three bands of dove-colored limestone	35
6. Limestone ; hard, blue-gray and soft yellow ; top bed dove-colored ; beds 6"-1' ; fossiliferous	65
7. Sandstone ; coarse, clear and white, well-rounded grains	40
8. Sandstone ; medium-grained ; gray to green ; rounded, clear, green and red grains ; massive ; hard to medium. Dip N.E. \angle 48°	40
9. Sandstone ; soft ; medium to coarse ; purplish to gray, top greenish ; quartz grains, clear, red, green, and black, besides specks of lime. Bed of lime (4') in middle. Sparingly fossiliferous. At top sandstone is harder and includes zone of brecciation	150
10. Sandstone ; massive ; medium-grained quartz, clear, green, red and black ; also lime specks ; all in green cement ; soft, but forms cliff face	13
11. Shale ; maroon, in part gray-green ; bed of soft sandstone at 50' ; some seams of limestone running across strike	100
12. Shale, gray-green	16

	Feet
13. Sandstone ; massive ; medium-grained ; quartz, lime and limonite, and a green stone in purple cement ; crumbles on weathering ; dip 34° in 30' (probably fault between numbers 13 and 14)	6
14. Shale ; maroon and gray-green ; one 2' pinkish bed ; lenses of coal	45
15. Sandstone ; or arenaceous limestone ; medium-grained ; beds 1'-3' ; hard, weathers in checks. Dip N. E. $\angle 45^{\circ}$	13
16. Coal (bloom) ; clean ; strike N. 25° W. ; dip N.E. $\angle 47^{\circ}$	$1\frac{1}{2}$
17. Limestone, gray ; thin-bedded ; with drab shale	60
18. Shale ; gray-green ; talus-covered	6
19. Limestone ; impure ; has plant fragments	2
20. Shale ; argillaceous ; drab-gray ; capped by 2' of arenaceous shale filled with plant remains	8
21. Sandstone ; fine-grained ; rounded quartz pebbles ; calcareous ; general color gray-white ; included beds and cap of gray-green ; soft, thin, even beds ; one belt of gray shale ; very few round, pea-sized limonite concretions. Dip N.E. $\angle 40^{\circ}$	85
22. Sandstone ; white ; coarse to medium, with clear, subangular quartz pebbles. Some bands almost a conglomerate. Soft, massive, weathers in rounded knobs. Hard to tell from No. 13 at contact, but No. 13 is finer and has lines of shale	100
23. Coal. Four feet bone in middle ; weathered gray ; fair quality. Dip N.E. $\angle 39^{\circ}$	8
24. Limestone ; thin-bedded, grading into sandstone at top ; interbedded with shale ; much checked or broken ; weathers gray or red-brown	30
25. Sandstone ; fine grain ; clear quartz, well-rounded and white flakes ; more lime near top than bottom. Color white with some buff-yellow bands ; massive ; many cracks across bedding. Like No. 33 except for absence of specks of carbonaceous matter	70
26. Sandstone ; fine-grained ; clear quartz, rounded and white flakes ; weathers yellow-brown ; fresh buff-gray. Even-bedded 1"-3'. One soft lens of buff-brown ; at top is a yellow band of limonite	35
27. Like No. 29, but limestone grades into a sandstone with fine, rounded quartz grains at top ; brownish gray ; mica on bedding planes	70
28. Gray shale ; contains lenses of limestone like No. 32 from 3" to 1' thick ; has two seams of coal, one $1\frac{1}{2}$ " about 11' from bottom, the other 13" ; very clean bloom at top	16
29. Limestone and shale ; limestone like No. 30. Slate greenish gray ; very thin-bedded ; mica on bedding planes	61
30. Sandy limestone ; buff-gray ; weathers mottled gray and red-brown. Thin, regular bedding	30
31. Shale ; gray ; with 2' red-brown limestone 8' from bottom,	25

	Feet
32. Limestone; begins as limy sandstone and ends as limestone; first beds buff to gray; last beds blue-gray (fresh fractured); beds even; 2"-3'; heaviest beds near bottom; much mica on bedding planes; fracture uneven and often breaks in rounded forms; between beds a parting of gray shale. Top contains limonite concretions like No. 33, and is weathered brown	50
33. Sandstone; fine-grained at top, medium at bottom; quartz grains rounded, not colored; a few tiny muscovite flakes and occasional black specks of carbonaceous matter. Much white lime or decomposed feldspar. Rare pea-sized pebbles of quartz; gray-white on weathered surfaces; soft, weather-rounded; bedding massive; cross-bedding poorly developed; contains seams of limonite-stained rock; one little streak of quartz showing garnet; round limonite concretions, size of pinhead to small pea; at 130' bed of shale about 32' thick. Shale is gray-drab to drab; contains carbonaceous matter, clear quartz grains, and occasional flakes of mica. Strike N. 24° W.; dip N.E. \angle 43°	275

SECTION C.

*Tuana Bay.**Strike N. 45° W; dip N. E. \angle 50°.*

	Feet
1. White, cross-bedded sandstone	10
2. Shale and thin sandstone; a few very thin carbonaceous layers	20
3. Sandstone; white, cross-bedded	60
4. Sandstone and sandy shales; thin-bedded; with plant fragments irregularly distributed	40
5. Shale, carbonaceous; coal in wavy lenses constitutes about $\frac{1}{3}$ of the stratum; the remainder consists of lignite intimately mixed with shale and sandstone; coal appears to be of good quality	4
6. Drab shales and sandstone like No. 8	20
7. Carbonaceous bed, one-half shale; abundant pyrite	4
8. Sandstone, gray, thin-bedded, $\frac{1}{2}$ "-2"; shales, black and drab; wavy, cross-bedded; concretionary; with ripple-marks arranged in overlapping patches a few inches in diameter; contains muscovite and a few plant impressions	200

The interleaving lense character of the coal is well shown here; 500' distant, across a little bay, numbers 5 and 8 are scarcely represented and shale occupies nearly the whole section.

SECTION D.

North end of Copacabana Peninsula, measured along the lake shore. Strike N. 40° W; dip E. 30°.

	Feet
1. Shales and thin sandstones with three beds of carbonaceous shale, 3', 4', 4' in thickness. Approximately one-half of each bed consists of coal of commercial value....	200
2. Sandstone; gray-white; cross-bedded.....	60
3. Shales, sandy; alternating with very thin ($\frac{1}{2}$ "- $1\frac{1}{2}$ ") beds of drab and gray sandstone; rare streaks of carbonaceous material.....	35
4. Shales, black; alternating with gray-brown sandstone in lenses, and cross-bedded shale, in part carbonaceous; with some thin ($\frac{1}{2}$ " \pm) lenses of true coal. At top is 1' \pm of impure coal.....	20
5. Shale; black, lumpy, in part stained by limonite; breaks in flakes; contains lenses of gray-brown sandstone....	20
6. Sandstone; yellow-gray; in 6"-10" beds.....	9
7. Shale; black to drab; like No. 9.....	20
8. Sandstone; yellow-gray.....	4
9. Shales; drab; thin-bedded ($\frac{1}{8}$ ") concretionary with wavy surfaces.....	6
10. Sandstone; yellow-brown; thin bedded (1"-4"); cross-bedded, micaceous, lumpy, with mud concretions and sun-cracks; surface of sandstone wavy and beautifully ripple-marked. Shales; drab, sandy, lumpy, intricately folded on minute scale.....	30
11. Sandstone; yellow; in beds 4"-10" thick; interbedded with drab, arenaceous shales. Bedding very uneven and surface of each stratum reveals overlapping flakes.....	15
12. Shales; brown, yellow and drab; with uneven, flaky surfaces.....	25
13. Sandstone; white to gray; cross-bedded; medium-fine grain; in beds 4'-6'.....	30

SECTION E.

Coal Mine at Yampupata, Copacabana Peninsula.

Measured by K. C. Heald.	Feet
1. Sandstone; medium-grained quartz, red and white; cement green; general color green; soft.....	10
2. Sandstone; fine to medium; rounded red and white quartz; cement a maroon color; general color purplish; soft.....	100
3. Sandstone; fine-grained; rounded quartz; slightly cross-bedded; beds about 1' thick.....	5
4. Shale; gray.....	3
5. Sandstone; medium-grained, brownish white; soft; cross-bedded, massive.....	6

	Feet
6. Shale ; purplish drab ; full of plant fragments ; two thin beds of limestone included	20
7. Shale and thin-bedded limestone ; transverse seams stained with limonite	175
8. Sandstone ; medium-grained quartz, clear, subangular to rounded ; occasional large grains ; some lime ; gray-white with limonite stains ; cross-bedded ; thin to heavy ; some rare spots of conglomerate	267
9. Sandstone ; fine-grained, rounded quartz ; much stained by limonite ; even-bedded ; mica on bedding planes	50
10. Shale ; drab with lenses of yellowish limestone	4
11. Limestone ; gray, sandy	$\frac{1}{2}$
12. Coal, with 2' band of sandstone. Coal of fair quality and with little "bone"	2
13. Shale ; gray to drab with purple streaks resembling rootlets	8
14. Sandstone ; fine-grained, with clear, rounded, quartz pebbles, white flakes and limonite ; even, heavy beds ; toward top assumes greenish tone and contains much mica and lime	20
15. Shale ; gray to purple	30
16. Sandstone ; fine, with well-rounded quartz grains, and white specks ; some muscovite ; thin, even bedding	6
17. Shale ; gray, with thin beds of limestone	40
18. Sandstone ; fine, with clear, well-rounded quartz grains and white specks. Mica on bedding planes ; weathers gray-white ; some raised veins of harder, dark rock ; bedding fairly even ; some cross-bedding ; some twisted beds ; calcareous at top	135
19. Limestone and shale ; the latter predominate ; shale is drab ; limestone is gray, to a limonite yellow ; cross-bedded and twisted ; has much mica on bedding planes	55
20. Sandstone ; fine, with rounded, clear grains of quartz, and numerous blotches of lime or other white material ; general weathered color gray-white with spots and bands of yellow ; medium hard ; even-bedded ; massive ; occasional small, rounded concretions of limonite. Strike N 46° W ; dip N. E. \angle 40°	30

Bibliography.

- Adams, G. I. : An Outline Review of the Geology of Peru. Report of the Smithsonian Institution for 1908, pp. 385-430.
- Agassiz, A. : Hydrographic Sketch of Lake Titicaca. Proc. Am. Acad. Arts and Sci., Vol. XI, 1875-76, pp. 283-292, with map.
- " and S. W. Garman : Exploration of Lake Titicaca. Bull. Mus. Comp. Zool. Harv. Coll., Vol. III, 1871-76, pp. 274-285.
- Bandelier, A. F. : The Islands of Titicaca and Koati, pp. 1-358. The Hispanic Society of America, 1910. The most exhaustive study yet made of any portion of the Titicaca region. While chiefly archæological, the volume contains valuable geographic data.
- Basadre, Modesto : Los Lagos de Titicaca. Bol. Soc. Geog. de Lima, Tomo III, 1894.

- Bowman, Isaiah : The Physiography of the Central Andes. This Jour., Vol. XXVIII, pp. 197-217, 373-402, 1909.
- Conway, Martin : Climbing and Exploration in the Bolivian Andes. New York, 1901.
- Dereims : Excursiones Cientificas, 1901-04. Anexo de la Memoria de Gobierno y Fomento. La Paz, 1906.
- D'Orbigny : Voyage dans L'Amerique Meridionale, Tomo III, Pt. III, Paris, 1842. Spanish edition translated and annotated by Victor E. Marchant, La Paz, 1907.
- Forbes : On the Geology of Bolivia and Southern Peru. Quart. Jour. Geol. Soc., Vol. XVII, 1861 ; Spanish translation by Edmundo Sologuren, Sociedad Geographica de La Paz, 1901.
- Le Maire, Dr. M. Neveu : Les Lacs des Hauts Plateaux de L'Amerique du Sud. Paris, 1906. Spanish translation by Dr. B. Diaz Romero, Direccion General de Estadistica y Estudios Geograficos, La Paz, 1909. A study by modern methods of the lake and its waters.
- Markham : The Land of the Incas. Geog. Jour., Vol. XXXVI, pp. 381-396, 1910.
- Orton : The Andes and the Amazon, 1873.
- Posnansky, A. : Lorenzo Zundt y la Geologia Boliviana. Bol. Oficini Nacional de Estadística, Nos. 70-72, pp. 288-295, 1912 ; El Clima del Altiplano y la Extension del Lago Titicaca. Bol. Oficina Nacional de Estadística, No. 64-66, La Paz, 1911.
- Puente, Ygnacio la : Estudio Monografico del Lago Titicaca bajo su aspecto fisico e historico. Bol. Soc. Geog. de Lima, Tomo I, 1892.
- Salter, J. W. : On the Fossils from the High Andes, collected by David Forbes. Quart. Jour. Geol. Soc., Vol. XVII, 1861.
- Squier, E. G. : Peru : Incidents of Travel and Exploration in the Land of the Incas.
- Steinmann : A Sketch of the Geology of South America. Am. Naturalist, 1891, pp. 855-860 ; also, Rosenbusch Festschriften, 1906, pp. 335-368.
- “ und Hoek : Das Silur und Cambrian des Hochlandes von Bolivia und ihre Fauna. Neues Jahrbuch für Mineralogie, Vol. XXXIV, 1912.
- Tovar, Augustin : Lago Titicaca : Observaciones sobre la disminucion progresiva de sus Aguas. Bol. Soc. Geog. de Lima, Tomo I, 1892.
- Short articles and statistical reports issued by the Bolivian and Peruvian governments.
- Ulrich : Paleozoische Versteinerungen aus Bolivia. Neues Jahrbuch, Vol. VII, 1892.
- Various articles and notes in the Bolletin Sociedad Geographica de Lima.
- Viscarra : Copacabana de los Incas. La Paz, 1901.
- Zundt, Lorenzo : El Lago Titicaca. Bol. Oficina Nacional de Estadística, Nos. 70-72. La Paz, 1912, pp. 222-226 : Appendix, Estudios sobre la Geologia de Bolivia por A. D'Orbigny. La Paz, 1907, pp. 65-104.

ART. XXIV.—*Experiments on Columnar Ionization*; by E. M. WELLISCH, Assistant Professor of Physics, Yale University, and J. W. WOODROW, Ph.D., Yale University.

INTRODUCTION.

1. In their experiments on the distribution of the active deposit of radium in an electric field, Wellisch and Bronson* found that the fraction of the total amount of active deposit that settled on the cathode increased with the potential-difference in a manner quite similar to the increase of the electric current which passed through the gas during the process of activation. The curve connecting the cathode activity and the potential-difference exhibited the characteristic 'lack of saturation' which had previously been investigated by Bragg, Moulin, and others in the case of the electric current due to alpha-ray ionization. This experimental result suggested the probability that the electric current would attain its saturation value only when all the active deposit settled on the cathode; or more generally, that the cathode activity was a measure of the degree of the saturation of the electric current.

On investigating experimentally the activity distribution when the radium emanation was present in air at a pressure of 260^{mm}, it was found that for potentials above 80 volts the cathode activity did not perceptibly increase; but the curves connecting the percentage of cathode activity and the ionization with the potential-difference had the characteristic horizontal portion which suggests that saturation has been attained. On the other hand, the measurements showed that there was still about 17 per cent of the active deposit which failed to reach the cathode.

These experimental results appeared to indicate that the saturation obtained for alpha-particle ionization at pressures below about one-half of an atmosphere was only apparent: the results were most suitably explained on the supposition that part of the electric current observed at one atmosphere was due to the ionization by collision with molecules which, though electrically neutral, had been brought into an unstable condition by the action of the alpha particle. These 'neutrons' would be in the most favorable position for ionization when the electric field was parallel to the alpha-ray column and also when the pressure was not too low.

On this view, the characteristic upward slope of the curve connecting the electric current with the field for alpha particle

* Wellisch and Bronson, *Phil. Mag.* (6), xxiii, p. 714, May, 1912.

ionization is due in part to the extra ionization thus obtained. We should expect, therefore, that when the electric force is sufficiently great the electric current would be slightly greater when the field is longitudinal or parallel to the alpha-particle column than when it is transverse or perpendicular to it. The present paper describes a series of experiments which were devised to compare the ionization resulting from a longitudinal and transverse field for the case of a single alpha-particle column. The results of the experiments confirm the accepted view of the phenomenon as advanced by Langevin and Moulin,* namely that the 'lack of saturation' of the ionization current is due to the columnar recombination, and no evidence was obtained which would indicate the existence of unstable atoms in the alpha-ray columns.

In Section 5, some theoretical considerations based on Langevin's theory of recombination are given in which the subject is treated from a slightly different standpoint from that adopted by Moulin.

DESCRIPTION OF THE EXPERIMENTAL METHOD.

2. It was first shown by Moulin that lack of saturation does not come into evidence when the field is transverse to the alpha-ray column nor, at low pressures, when the field is longitudinal. This experimental fact formed the basis of the method employed for the comparison of the ionization resulting from the application of a longitudinal and a transverse field to a single alpha-particle column.

Consider a single alpha-particle column formed in air (1) at a pressure of one atmosphere, (2) at a pressure p which is a small fraction of an atmosphere, say about one-third. Let i_1 and i_2 denote the number of ions due to a small portion of the path (in the present case this was 4^{mm} in length) for the two pressures respectively. This ionization may be measured with either a longitudinal or a transverse field. Let

$$\frac{i_1}{i_2} = r_l \quad \text{and} \quad \frac{i_1}{i_2} = r_t$$

when the ionization is measured in a longitudinal and transverse field respectively.

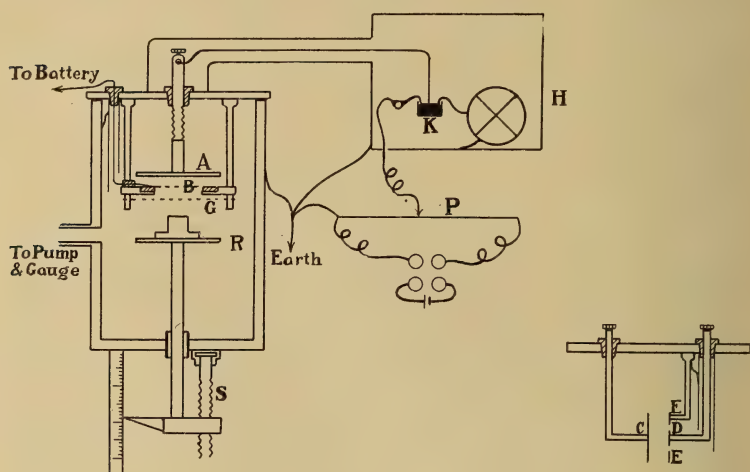
In general, r_t will be different from r_l : this arises from the fact that the current at one atmosphere when measured in the longitudinal field depends upon the electric field over a wide range, while in the other the currents readily assume values which are independent of the field.

* Moulin, *Comp. Rend.*, cxlviii, p. 1757, 1909.

On the hypothesis of Wellisch and Bronson it was to be expected that r_l would be greater than r_t for large values of the field; whereas on the Langevin-Moulin theory r_l should be less than r_t , except when saturation was attained, in which case we should have $r_l = r_t$.

In order to determine the value of r_l corresponding to any value of the field, the ionization currents due to the alpha rays from a polonium source were measured in a longitudinal field for air at one atmosphere and for air at a lower pressure p . The ratio of these currents gives the value of r_l and is independent of the actual number of alpha particles entering the

FIG. 1.



measuring apparatus and also of the electrical capacity of the system: in fact it is the ratio which would be obtained for the ionization due to a single alpha particle.

The ratio r_t was obtained in a similar manner by obtaining the corresponding currents in the transverse field.

Description of Apparatus and Experimental Procedure.

3. By the kind permission of Prof. Bumstead we were enabled to avail ourselves of the ionization vessel which had previously been employed by Wheelock* in his experiments on alpha-ray ionization. A general idea of the apparatus and the general scheme of connections may be obtained from fig. 1. For the vertical longitudinal field the ionization vessel consisted of a wire gauze B, 7.5 cm in diameter, situated 4 mm below a cir-

* Wheelock, this Journal (4), xxx, p. 233, 1910.

cular brass plate A, which was connected to one pair of quadrants of a Dolezalek electrometer. The lower gauze G was inserted as usual, to avoid disturbances due to diffusion of ions into the region AB.

For the horizontal transverse field two brass plates were employed, one C ($8.5 \times 2.5^{\text{cm}}$) connected to the battery, and the other D ($7.2 \times 0.4^{\text{cm}}$), which connected with the electrometer. The latter electrode was surrounded by an earthed plate E, which served as a guard ring.

Both the longitudinal and the transverse fields were so constructed that they could be inserted in the same containing vessel, as shown in the diagram.

A thin film of polonium deposited on a copper plug, 4^{mm} in diameter, which had been prepared previously by Prof. Boltwood, was employed as the alpha-ray source. This plug was placed on the carrier R, which could be moved vertically by a screw, S. A scale and divided head enabled one to make a very accurate determination of the distance of the polonium from the center of the ionization vessel. A narrow beam of alpha-rays was always employed; this was obtained by placing over the polonium a fine slit or a series of fine 'canals' as described below.

The electrometer was of the Dolezalek pattern with a platinum suspension, and had a sensibility of 140^{mm} per volt with 84 volts on the needle.

In most of the experiments a potentiometer arrangement was employed so that the reading of the ionization current might be made with the zero of the instrument at the center of the swing. It was found that this method gave very consistent and accurate readings, which was of especial importance when small potentials were employed.

The whole apparatus could be rendered gas-tight by the use of a heavy stop-cock grease.

Experimental Results.

4. In the first set of observations a fine slit 5^{mm} long and 0.5^{mm} in width was placed 1^{cm} above the surface of the polonium. A 'Bragg' curve was determined in the usual manner by varying the distance of the polonium from the electrodes. The range of the alpha particle in air at one atmosphere or a pressure of 760^{mm} of mercury was found to be 3.8^{cm} , which is in good agreement with that observed by Levin* and Taylor†. When the transverse field was employed the slit was so orientated that its length was parallel to the electrodes. It was cal-

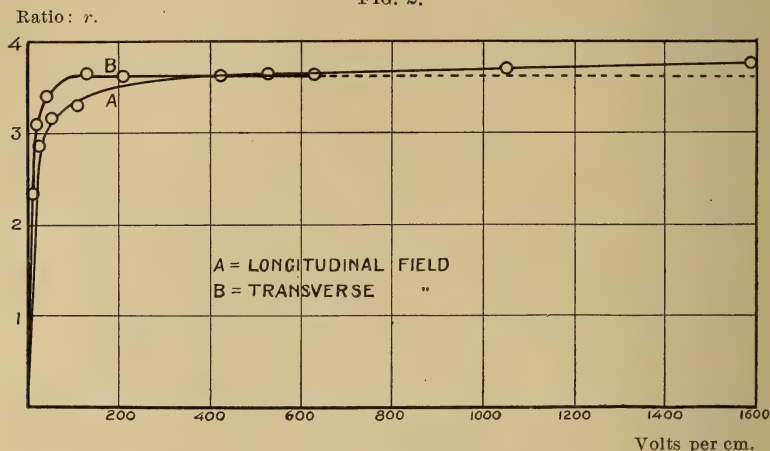
* Levin, this Journal (4), xxii, p. 8, 1906.

† Taylor, *ibid.* (4), xxvi, p. 169, 1908.

culated that the cone of rays emerging from the slit would fall entirely within the electrodes and that no alpha particle could reach an electrode except by scattering.

The values obtained for r_i and r_e for different values of the electric field X are given below, and the corresponding curves are given in fig. 2. The values given for the ratio r are for

FIG. 2.



the ratio of the current at a pressure of 760^{mm} to that at a pressure of 284^{mm}. The distance $d = 2.68$ cm is that from the polonium to the middle of the ionization vessel. This notation will be used throughout the present paper. The current is in scale divisions per second.

TABLE I.

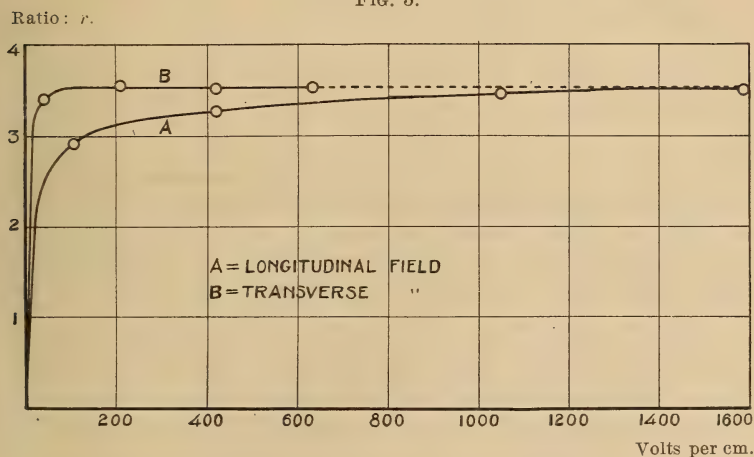
$$d = 2.68 \text{ cm.}; r = i_{760}/i_{284}.$$

p mm.	Longitudinal Field.			Transverse Field.		
	X volts/cm.	i_i	r_i	X	i_e	r_e
160	1565	0.65		625	0.43	
284	1565	1.22		625	0.82	
770	25	3.51	2.88	4	1.91	2.33
770	50	3.88	3.18	20	2.53	3.09
770	105	4.05	3.32	42	2.80	3.42
770	525	4.46	3.66	125	2.99	3.65
770	1045	4.53	3.71	210	2.96	3.62
770	1575	4.61	3.78	625	2.98	3.64

It will be seen from fig. 3 that for values of X greater than 400 volts per centimeter r_t is greater than r_l . This experimental result was verified in several subsequent determinations and appeared thus to support the view that there is extra ionization produced when the electric field is longitudinal.

The slit was now removed and in its place was inserted a 'canal' system consisting of twenty-five small holes drilled in a small brass rod 6^{mm} in length and 4^{mm} in diameter. There was a central 'canal' 1^{mm} in diameter surrounded by twenty-four smaller 'canals,' each 0.4^{mm} in diameter. In this manner the electric field was more rigorously longitudinal or transverse to the alpha-particle trajectories than when the slit was employed. A value was obtained for the range of the alpha-particle identical with that found previously.

FIG. 3.



The values obtained for r_l and r_t are given in Table II, and the corresponding curves are shown in fig. 3.

TABLE II.

$$d=2.6 \text{ cm.}; r=i_{760}/i_{261}.$$

p .	Longitudinal Field.			Transverse Field.		
	X .	i_l .	r_l .	X .	i_t .	r_t .
261	1580	0.385		630	0.435	
400	1580	0.610		530	0.685	
760	105	1.13	2.94	42	1.48	3.40
760	420	1.26	3.28	210	1.54	3.54
760	1050	1.32	3.43	420	1.53	3.52
760	1580	1.34	3.48	630	1.53	3.52

In order to determine whether the scattering of the alpha-particles produced any effect on the relative values of r_l and r_t when the canals were employed, readings were taken of the current with the polonium at different distances from the middle of the ionization vessel. The electric field was 1580 volts per centimeter for both the longitudinal and the transverse fields. The results are shown in Table III.

It will be seen now that in every case the value of r_t is greater than the corresponding value of r_l . The curves of fig. 3 tend to the same maximum value, namely, 3.53.

TABLE III.

$X_l=1580$ volts/cm.; $X_t=630$ volts/cm.; $r=i_{760}/i_{284}$.

$d.$	$r_l.$	$r_t.$	$d.$	$r_l.$	$r_t.$
3.2 cm.	3.04	3.08	2.8 cm.	3.27	3.34
3.0 cm.	3.30	3.37	2.6 cm.	3.11	3.28

In order to ascertain the reason for the discrepancy between the results obtained when the slit and the canals were employed, experiments were performed in which only small portions of the slit previously employed were effective. The oblique rays were eliminated by placing narrow pieces of brass over the ends of the slit so as to leave an opening in the center 1.7^{mm} in length and 0.5^{mm} in width. The corresponding values of r_l and r_t are given in Table IV: it will be seen that the ratios for the longitudinal and transverse fields have approximately the same maximum values. The results thus serve to confirm those obtained when the canals were employed.

TABLE IV.

$d=2.68$ cm.; $r=i_{760}/i_p$.

$p.$	Longitudinal Field.			Transverse Field.		
	X.	$i_l.$	$r_l.$	X.	$i_t.$	$r_t.$
284 mm.	1580	0.560	3.42	630	0.391	3.40
400	1580	0.828	2.24	630	0.588	2.27
596	1580	1.370	1.40	630	0.962	1.38
760	1580	1.914	1.00	630	1.330	1.00

The narrow brass pieces were now removed from the ends of the slit and a brass plate 2^{mm} in width was placed over the central portion of the slit so that now the ionization was mostly due to the oblique rays. The values of r_l and r_t are tabulated in Table V. The fact that r_l is much greater than r_t for high values of the electric field shows that the oblique rays were responsible for the small values of r_t relatively to those of r_l when the whole slit was employed as described above.

TABLE V.
Oblique rays. $d=2.68$ cm.; $r=i_{760}/i_{284}$.

<i>p.</i>	Longitudinal Field.			Transverse Field.		
	X.	<i>i_l</i> .	<i>r_l</i> .	X.	<i>i_t</i> .	<i>r_t</i> .
284	1580	0.917		630	0.808	
760	420	3.04	3.31	630	2.55	3.16
760	1580	3.15	3.45			

In order to examine more closely the effect when the oblique rays alone were made effective by eliminating those from the central portion of the slit, readings were taken of the ionization current for different gas pressures in both the longitudinal and transverse fields. From the figures given in Table VI, one sees that the increase of the current with the pressure is quite normal in the case of the longitudinal field, but that the current at a pressure of 760^{mm} of mercury in the transverse field shows a distinct falling off from the normal law. This result was surprising in view of the calculations for the position of the cone of rays emerging from the slit. It indicates probably that an appreciable fraction of the alpha particles are scattered into the electrodes of the transverse field, thus diminishing the ionization current. In the longitudinal field there would not be a diminution of the current, as the particles would be merely scattered in the gas.

The experimental results obtained when the rays were canalized are thus the only results which admit of strict interpretation; and they show that r_l and r_t both tend to the same maximum value. In other words, in accordance with the view generally accepted, the current resulting from alpha-ray ionization has the same saturation value whether the electric field is longitudinal or transverse, the continued slope of the ionization curve for the longitudinal field being due entirely to 'lack of saturation' occasioned by the recombination of ions.

TABLE VI.

Oblique rays. $d=2.68$ cm.; $X_1=1580$; $X_2=630$.

p .	i_1 .	i_2 .	i_1/p .	i_2/p .	i_1/i_2 .
mm.					
153 ₉	0.47	0.41	3.07×10^{-3}	2.68×10^{-3}	1.14
232	0.73	0.65	3.14 "	2.80 "	1.12
261	0.84	0.74	3.22 "	2.84 "	1.13
284	0.92	0.81	3.24 "	2.85 "	1.13
370	1.24	1.10	3.36 "	2.98 "	1.13
400	1.36	1.21	3.40 "	3.03 "	1.12
446	1.56	1.39	3.50 "	3.12 "	1.12
596	2.25	1.99	3.77 "	3.34 "	1.13
760	3.15	2.55	4.15 "	3.38 "	1.23

It is worthy of mention here that experiments were performed to determine the shape of the ionization curve in the longitudinal field at pressures of about 10^{mm} of mercury when the electric field was sufficiently increased to produce ionization by collision. The curve obtained was that to be expected from Townsend's theory and no evidence of any anomalous behavior was observed.

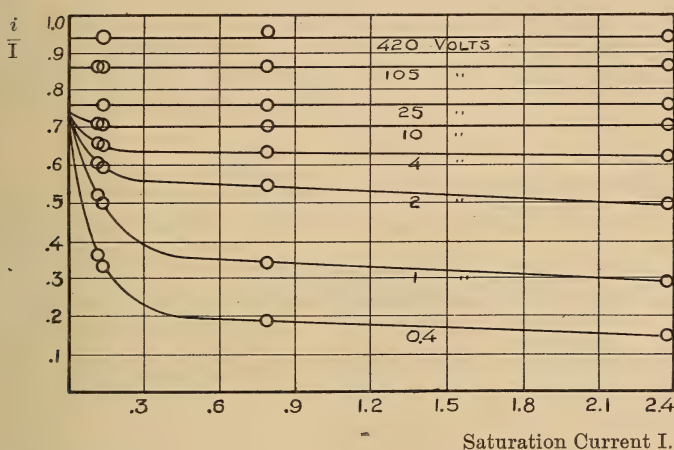
Having proved to our satisfaction that the characteristic shape of the ionization curve for the longitudinal field was to be ascribed entirely to the effect of recombination of ions, it became a point of interest to ascertain if possible the relative effects of columnar and volume recombination. Moulin* has already given a method for determining the shape of the current-field curve when volume recombination is absent, that is, when no recombination takes place between ions formed in different columns. Moulin's method consisted in determining the effect of volume recombination by comparing the curve obtained for a transverse field with that obtained by using X-rays as the ionizing source. The ideal curve corresponding to absence of volume recombination in a longitudinal field was obtained by means of a series of calculations referred to the ideal curve of the transverse field.

In the present experiments a more direct method was employed to obtain these ideal curves for a longitudinal field. This method consisted in determining how the fraction (i/I) of the saturation current (I) which corresponds to any given value of the electric field depends upon the value of this saturation current. Three sources of polonium were employed and a fourth determination was possible as a result of an appreciable decay of the weakest of these sources. In fig. 4 are

* Moulin, Ann. Chim. Phys. (8), xxii, p. 26, 1911.

given curves which show how i/I varies with I for different values of X in the longitudinal field. The curves are plotted from the values given in Table VII. These curves are produced so as to intersect the axis of ordinates: the ordinates thus cut off represent the fraction of the saturation current

FIG. 4.



which would be obtained by the corresponding field in the absence of any recombination between ions of different columns.

It might be expected that as there are only four points on each curve it would be very difficult to produce the curves as

TABLE VII.
Longitudinal Field; $d=2.6$ cm.; $p=760$ mm.

X.	0.4	1.0	2.0	4.0	10	25	105	420	I.
i/I .	.36	.52	.605	.658	.710	.76	.86	.94	0.12
i/I .	.33	.50	.595	.654	.708	.76	.86	--	0.13
i/I .	.19	.34	.548	.635	.704	.76	.86	.96	0.78
i/I .	.15	.29	.498	.623	.704	.76	.86	.94	2.39

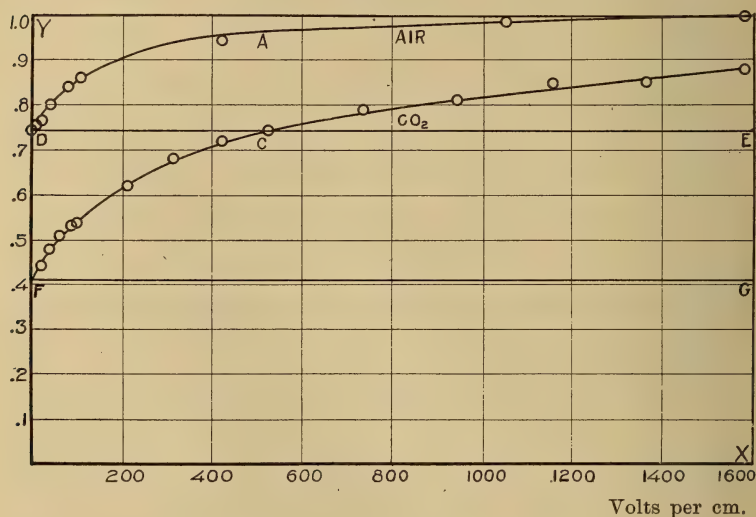
Transverse Field; $d=2.6$ cm.; $p=760$ mm.

X.	0.4	0.8	2.0	4.0	10	26	40	I.
i/I .	.25	.44	.68	.775	.872	.94	.98	0.44
i/I .	.09	.16	.38	.645	.816	.93	.97	2.40
i/I .	.05	.10	.25	.490	.783	.92	.97	6.99

stated above, especially those curves corresponding to small values of the field: however those points which were of the most importance for our subsequent calculations were those which were most readily obtained by this method. Moreover other considerations made it highly probable that the curves corresponding to the small values of the electric field intersected the axis of ordinates at points close to one another.

In fig. 5 the limiting values of i/I obtained as above described are plotted against the corresponding values of the electric field. This curve refers to the longitudinal field in air at a pressure of 760^{mm} of mercury and may be considered as giving the fraction of the total ionization produced by a single

FIG. 5.



alpha particle which is carried over to the electrodes by the corresponding electric field. The curve is practically identical with that obtained by Moulin;* it intersects the axis of ordinates at a point represented by the fraction 0.74. The ideal curve for the transverse electric field could not be obtained with the same degree of accuracy, but it is approximately a straight line parallel to the X-axis and with 1.0 as ordinate, indicating that a very small value of the field is sufficient to prevent recombination of the ions.

In fig. 5 is also given a curve obtained by the direct measurement of the ionization current in the longitudinal field when the gas in the vessel was CO₂ (carefully dried) at a pressure of

* Moulin, loc. cit., p. 99.

750^{mm} of mercury, the polonium being at a distance of 1.75^{cm} from the center of the ionization vessel. This curve represents very accurately the limiting curve for CO₂ corresponding to the ionization by a single alpha particle. It seemed unnecessary to obtain the limiting points in the manner employed in the case of air inasmuch as the shape of the curve for CO₂ is determined almost entirely by values of the electric field which are easily able to prevent volume recombination. This curve was also in good agreement with that obtained by Moulin. The saturation current for CO₂ was not obtainable experimentally; its value was calculated by means of a formula given by Langevin, as is indicated in the following section.

THEORETICAL CONSIDERATIONS.

5. According to the view brought forward by Moulin† the saturation current is obtained for alpha-ray ionization only when the component of the electric field perpendicular to the alpha-particle column has a value which is sufficient to separate the ions before recombination occurs. After the column has been formed two effects are operative which tend to separate the ions; namely diffusion combined with molecular agitation, and the transverse component of the electric field. Moulin distinctly states that a field strictly longitudinal has no effect in breaking up the columns; that the reason the saturation current is attained in practice for longitudinal fields is that these fields really have a component perpendicular to the trajectories. He has also shown by calculations based on the geometrical conditions of his apparatus that when the saturation current is attained in such a longitudinal field the transverse component of the field has the same value as would be necessary to secure saturation in a transverse field. With a field which is strictly longitudinal on his view we should obtain only that fraction of the saturation current which is due to diffusion. Curve A, fig. 5, shows that this fraction is approximately 0.74 for air at a pressure of one atmosphere, which is in good agreement with the value previously found by Moulin.

The excellent agreement which Moulin obtains between theory and experiment lends strong support to this view: at the same time we would like to indicate briefly a possible manner in which the ionization curve may be explained by introducing the part played by a strictly longitudinal field in preventing recombination. The fact that the shape of the curve obtained experimentally by us when the longitudinal field was employed is in such good agreement with that

† *L. c.*, p. 80.

obtained by Moulin, although the method of canalizing the rays was quite different (in the present case the extreme rays made an angle with the normal less than two-thirds the corresponding angle in Moulin's experiments), suggests that the longitudinal field does play a part in preventing recombination.

As stated previously, the curve A, fig. 5, gives us the 'ideal' curve corresponding to the ionization produced by a single alpha particle in a longitudinal field. The fact that a very small field whose value is just large enough to direct the ions brings 74 per cent of the ions to the electrodes shows that this percentage of the ions must escape quickly from the column as a result of diffusion and molecular agitation.

Let us draw through the point D, where the curve A intersects the axis of ordinates, a straight line DE parallel to the axis of X. If we now refer the curve A to DE and DY as axes, we may regard this curve as being a new saturation curve resulting from the application of increasing longitudinal fields to those ions in the column which have not been separated by the process of diffusion. Langevin's theory of recombination affords a ready means of testing the truth of this supposition. According to this theory, if the gas between two parallel electrodes is ionized by a single flash of rays of very short duration, then the quantity of electricity Q received at the electrodes corresponding to any field $X = 4\pi\sigma$ is given by

$$\frac{\epsilon Q}{\sigma} = \log_e \left(1 + \frac{\epsilon Q_0}{\sigma} \right) \quad (1)$$

where Q_0 is the total quantity of electricity liberated per sq. cm. of cross section and ϵ is a proper fraction which Langevin found by experiment to have the value 0.27 for air at a pressure of one atmosphere. If we revert to the case of a single alpha particle the time which it spends in ionizing is extremely small, and if we suppose the initial separation of the ions due to molecular agitation to be extremely rapid we have the ideal conditions for applying Langevin's theory of recombination.

In order to test the applicability of this theory, Langevin's equation was put in the form

$$y = \frac{1}{x} \log_e (1 + x) \quad (2)$$

where

$$y = Q/Q_0 \text{ and } x = \frac{\epsilon Q_0}{\sigma}.$$

Corresponding values of y and σ were chosen at various points along the curve A, fig. 5; from the value of y that of x was obtained by computation, using equation (2), and then making use of the relation $x = \frac{\epsilon Q_0}{\sigma}$, Q_0 was determined. The values of Q_0 obtained by choosing different values for y should be constant. A set of values determined in this way is given in Table VIII. The values of Q_0 are given in arbitrary units.

TABLE VIII.
Different Position of the Axis.

y	.73.		.74.		.75.	
	X Volts/cm.	Q_0 .	X.	Q_0 .	X.	Q_0 .
0.46	75	66.3	90	79.6	105	92.8
0.55	140	82.5	150	88.3	160	94.3
0.61	190	84.0	195	86.1	210	92.8
0.66	230	81.3	245	86.6	250	88.3
0.75	338	74.9	350	77.2	360	79.6
0.81	460	67.8	550	81.0	520	76.6

In order to obtain an idea of the sensibility of the method, two other straight lines parallel to DE and close to it were chosen as axes. The values of Q_0 obtained by choosing different values for y along the curve A when the axes were at 0.73, 0.74, and 0.75 are given in the above table. It will be seen that the values for the axis at 0.74 are more nearly constant than for the other two positions of this axis. With the axes farther away, the values differ much more; that is, the values of Q_0 are more nearly constant even for the large values of y when the axis is chosen so as to pass through the point where the curve appears to intersect the axis of ordinates.

Taking the straight line DE as the axis, the average of the values obtained for Q_0 is 82.3, which when reduced to E. S. units gives $Q_0 = 0.274$. Taylor* has determined the total number of ions produced by a single alpha particle from polonium in air at a pressure of one atmosphere: his calculations give this number to be 164,000. The ratio of the area of that portion of the 'Bragg' ionization curve, included between the two ordinates corresponding to distances 2.4^{cm} and 2.8^{cm} from the polonium, to the total area enclosed by the curve and the axes, was found to be 0.112. Then each alpha particle will

* Taylor, Phil. Mag. (6), *xxiii*, p. 670, 1912.

produce $0.112 \times 164,000 = 18,368$ pairs of ions in the ionization vessel employed in the experiments described above, where the polonium was 2.6 cm from the center of the vessel. Let S be the cross-sectional area of a column; then assuming uniform ionization within the column the total charge liberated by a single alpha particle in the region considered is

$$\frac{100}{26}SQ_0 = \frac{27.4}{26}S = 18368 \times 4.65 \times 10^{-10},$$

whence

$$S = 8.10 \times 10^{-6} \text{ cm}^2$$

and the radius of the cross-section becomes

$$R = 0.0016 \text{ cm}.$$

In the application of the theory to CO_2 , as the saturation current could not be obtained experimentally, recourse was had to the method described by Langevin* in his original paper. The ionization curve for CO_2 was drawn with electric field as abscissæ and current as ordinates: the curve was then produced to intersect the axis of ordinates. The straight line through this point parallel to the X-axis was taken as the new axis and the method of Langevin for finding ϵ was then applied.

A large curve given by the equation $y = \frac{1}{x} \log(1 + x)$

was plotted with $\log(x)$ as abscissæ and $\log(y)$ as ordinates. The value of the current (measured from the new axis) for an electric field of 1,575 volts per cm. was taken as Q' and then from different values of $\log(Q'/Q)$ corresponding to values of $\log(X'/X) = \log(\sigma'/\sigma)$, $\log(x)$ and $\log(y)$ could be read off on this curve. The determinations thus made of ϵ from the

equation $\epsilon = xy \frac{\sigma}{Q}$ (in arbitrary units) for different values of X are given in Table IX. From this mean value of $\epsilon = 2,032$, it was possible to determine by the use of equation (1) the value of the saturation current. The value given in Table IX

TABLE IX.

X	200	400	600	800	1000	∞
Q	0.181	0.260	0.301	0.331	0.356	0.525
ϵ	2030	1930	2050	1960	2190	

for $X = \infty$ was obtained in this way; and this value was employed in plotting the curve C, fig. 5, which is seen to intersect the axis of ordinates at the point corresponding to the fraction 0.41.

* Langevin, *Ann. Chim. Phys.* (7), xxviii, p. 458, 1903.

The value of Q_0 of the saturation current per sq. cm. for a single column can be readily deduced after the curve C has been plotted. Langevin found that for CO_2 at a pressure of one atmosphere $\epsilon = 0.51$; the values of y and x were obtained corresponding to a field of 200 volts per cm. and Q_0 was then

deduced by means of the relation $x = \frac{\epsilon Q_0}{\sigma}$. The value ob-

tained was $.551$ E. S. unit. The ionization current in CO_2 was measured at the same relative part of the range of the alpha particle as that in air; and assuming that the total ionization in CO_2 is 1.03 times that in air, it was easy to calculate the number of ions produced by each alpha particle within the ionization vessel. The calculation gave the area of cross-section $S = 1.42 \times 10^{-5} \text{ cm}^2$ and the radius of the column $R = 0.0021 \text{ cm}$.

The large values obtained for the mean cross-section of the columns may at first appear surprising. Professor Bumstead* has already suggested that a considerable part of the ionization in the columns may be indirect and be due to the action of electrons liberated from the atoms by the action of the alpha particle. These electrons would have a range of the order of 0.1 mm in air at a pressure of one atmosphere. Apart from this suggestion, however, it should be remembered that the cross-section is that of the column after the ions have in considerable measure been separated by the processes of diffusion and molecular agitation. After the column has been formed by the alpha particle there would in all probability be an extremely rapid lateral diffusion of the ions, so that before the ions have sensibly moved under the action of the electric field we may regard the column as consisting of a core (which in air at one atmosphere contains about 26 per cent of the ions) surrounded by a fringe. The recombination occurs mainly in the core.

If Langevin's theory is indeed applicable as the above considerations would appear to indicate, this would afford a further proof that the recombination in the alpha-particle columns is between ions formed from different atoms and is not the initial recombination in the sense originally understood by Bragg, viz., that between an electron and its parent atom. It is probable that such initial recombination does actually occur, but it does not appear to be prevented to any appreciable extent by the electric fields employed in ordinary laboratory practice.

* Bumstead and McGougan, *Phil. Mag.* (6), xxiv, p. 482, 1912.

Summary.

(1) A method was devised to compare the ionization due to a single alpha particle when measured in a longitudinal and transverse field. The results confirm the view of Moulin and Langevin that the upward slope characteristic of the alpha-ray ionization curve when a longitudinal field is employed, is due entirely to recombination of ions in the column. The suggestion of Wellisch and Bronson that the slope is due in part to ionization by collision is shown to be untenable.

(2) It is shown that Langevin's theory of recombination appears to be applicable to the ionization produced by a single alpha particle; also the theory enables an estimate of the mean cross-section of the column to be computed.

Sloane Laboratory, Yale University, June 4, 1913.

ART. XXV.—*Geology of the New Fossiliferous Horizon and the Underlying Rocks, in Littleton, New Hampshire*; by FREDERIC H. LAHEE.

CONTENTS.

	Page
Introduction	231
Summary	232
Geology of the Fitch Hill Section	234
The Lyman schists	234
The Fitch Hill granite gneiss	235
Earlier references	235
Distribution	235
Northern phase	235
Southern phase	238
Variations in mineral composition	238
Intrusive contact with the Lyman schists	239
Unconformable contact with Blueberry Mt. series	240
Blueberry Mountain series on Fitch Hill	241
Geology of the Blueberry Mountain series southwest of Fitch Hill	244
Distribution	244
Structure and Correlation	246
Devonian fossiliferous horizon	247

Introduction.

IN August, 1912, the writer published a notice of the discovery of a new fossiliferous horizon near Littleton, New Hampshire.* Further field work and subsequent laboratory study have furnished material for a more complete description of the geology of this region.†

The town of Littleton is 23 miles nearly due west from Mt. Washington, and is situated on the terraces of the Ammonoosuc River, about 22 miles from the point where this stream unites with the Connecticut River at Woodsville.

Two miles west of Littleton the land rises westward 1000 to 1200 feet above the Ammonoosuc River to a ridge known in its northern part as Blueberry Mountain and in its southern as Bald Hill. Blueberry Mountain has its northeastern end in a valley in which two brooks flow, one northwest to the Connecticut River, and the other southeast to the Ammonoosuc River (see fig. 1). A relatively small crest (not shown by the contours) at the northern end of Blueberry Mt. is known as Fitch Hill. This hill is just south of Locality 7, as shown in fig. 2.

* A New Fossiliferous Horizon on Blueberry Mt., in Littleton, New Hampshire, Science, N. S., xxxvi, p. 275, 1912.

† This geological investigation was undertaken with the aid of a fund provided through the generosity of Mr. R. W. Sayles, of the Harvard Geological Department.

The area to be described (fig. 2) is a strip $1\frac{1}{4}$ miles wide and $7\frac{1}{2}$ miles long, including Fitch Hill, Blueberry Mt., Bald Hill, and the country for four miles southwest of Bald Hill.

Blueberry Mt. and its vicinity should be of peculiar interest to the geologist because the rocks there are less metamorphosed than those anywhere else between the Connecticut River and the Franconia range of the White Mountains, and because most of the fossils obtained in northern New Hampshire have come from this locality.

In presenting the results of our field work we shall describe (1) the petrology, structure, and stratigraphic sequence of the

FIG. 1.

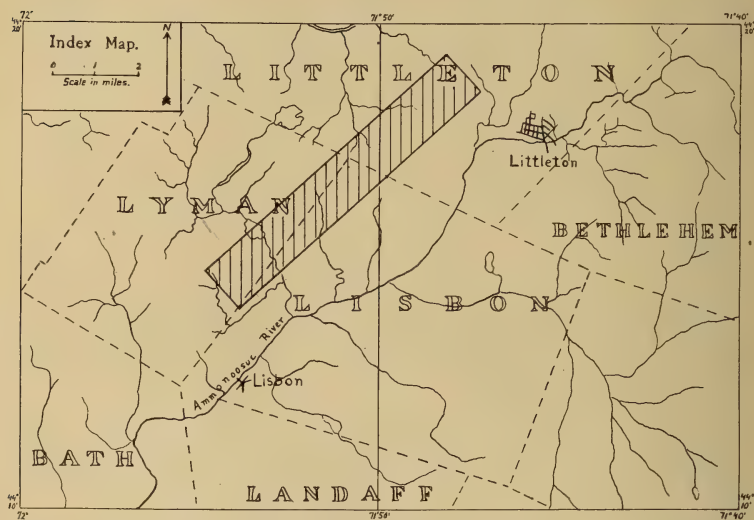


FIG. 1. Outline map of the Ammonoosuc district in New Hampshire, showing the position of the area (shaded) included in fig. 2.

rocks on and near Fitch Hill; (2) the southwestward distribution of these rocks; and (3) the new fossiliferous horizon of Blueberry Mt.

Summary.

Following is a summary of the essential facts set forth in this paper:

1. A metamorphic igneous rock, herein called the 'Fitch Hill granite gneiss,' outcropping in the township of Littleton, N. H., displays certain variations in mineral composition, which are possibly consequent upon original magmatic differentiation.

FIG. 2.

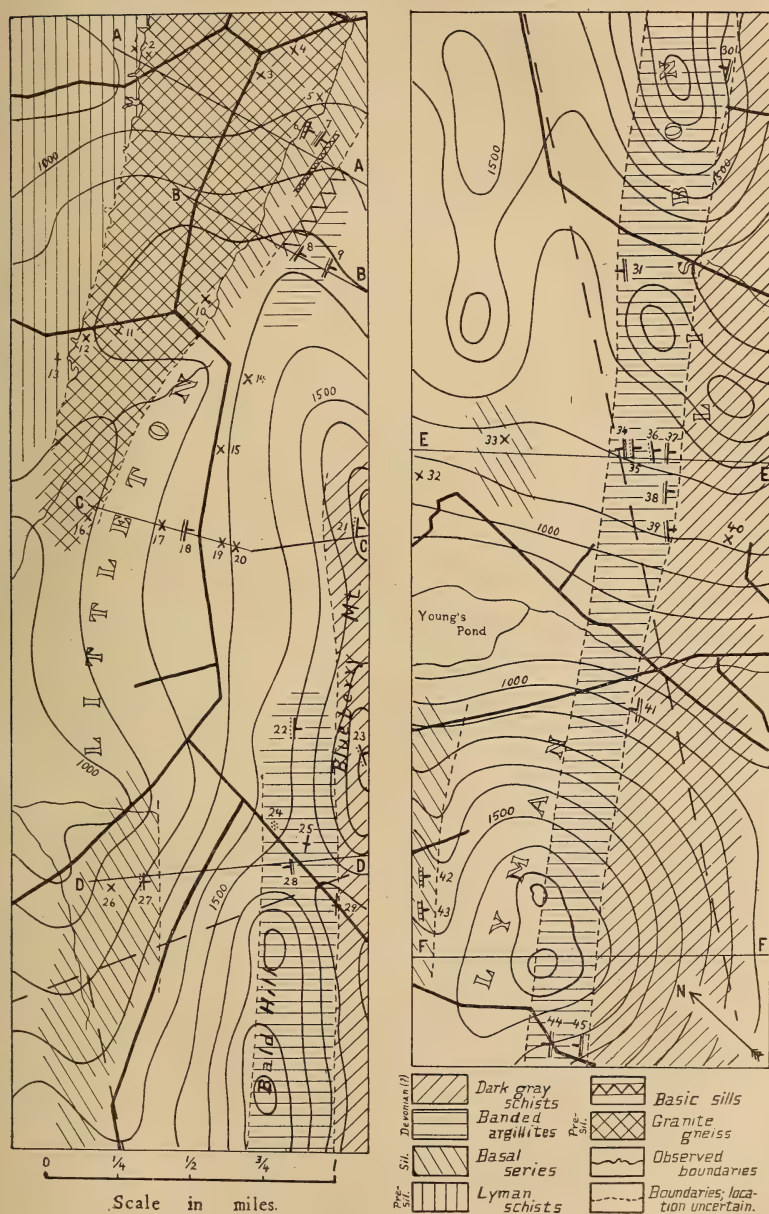


FIG. 2. Map of the area described in this report. The lower edge of the map on the left is the upper edge of that on the right. The positions of the cross-sections drawn in figs. 3 and 4 are marked by lines lettered A-A, B-B, etc.

2. The Fitch Hill granite gneiss is intrusive into the Lyman schists, but unconformably underlies the Niagaran sediments of Fitch Hill, Littleton, thus demonstrating the presence of a regional unconformity beneath the Upper Silurian strata of the Ammonoosuc district in New Hampshire.

3. The limestone near the base of this Upper Silurian formation is, at least in part, a conglomerate composed of roundish pebbles of crinoidal limestone, together with a very few pebbles of granite, in a highly calcareous, argillaceous, coral-bearing paste.

4. Marine fossils of Devonian age—presumably Lower Devonian—have been discovered in fine-grained clastics ('banded argillites') about 3000 feet above the base of the Upper Silurian in this region. These Devonian strata may be followed for seven or eight miles along their strike, but they grow finer and more metamorphosed southwestward. Fossils have been found in them at four localities within a distance of five miles along the strike. These fossils confirm the belief, long ago stated, of a seaway situated near the Connecticut River valley in Devonian times.

Geology of the Fitch Hill Section.

In fig. 3 is shown a vertical section drawn nearly north and south across the strikes of the Fitch Hill rocks. Its position is indicated in fig. 2 by the line A-A. Its southern end cuts through Fitch Hill. The rocks appearing in this section are the Lyman schists, the Fitch Hill granite gneiss, and a group of strata which may be called the Blueberry Mountain series.

The Lyman schists.—The terms 'Lyman schists' and 'Lyman group' were applied by Professor Hitchcock to a body of 'hydro-mica and chlorite schists' which in his earlier report* he assigned to the Huronian. Writing 30 years later,† he referred the group to the Cambrian or Ordovician, but not with complete assurance, for the structural relations of the formation are obscure and all possible evidence of fossils has been destroyed by metamorphism.

These Lyman schists outcrop in the northern corner of the map (fig. 2). They are highly metamorphosed fine-grained sandstones and mudstones, with a few beds of fine conglomerate in which the pebbles, all angular and mashed, are hardly distinguishable from the paste. Some of the finer schists are thinly banded, and these strata bear evidence of great contortion. In one place a zone of crush-conglomerate was seen.

* Hitchcock, C. H.: *Geology of New Hampshire*, vol. ii, p. 50, etc., 1877. *Ibid.*, *Geology of Northern New England*, p. 12, 1874.

† *Geology of Littleton, New Hampshire*, reprint from the *History of Littleton*, pp. 11 and 29, 1905.

The series as a whole is drab or greenish gray in color. Weathered surfaces are much lighter, sometimes almost white.

The Fitch Hill granite gneiss: Earlier references.—While this rock has been mentioned several times in previous writings on the Littleton district, it has never received very thorough consideration, nor have its relations to the adjoining formations been described. In Hitchcock's works it is called 'chlorite,'* 'chlorite rock,'† 'chloritic foliated granite,'‡ and 'protogene,'§ a name given to it by Hawes. Lambert refers to it as a "stratum of igneous rock,"|| and also merely as "igneous rock."¶

Distribution.—The Fitch Hill granite gneiss outcrops in a belt which trends N.E.—S.W., to the south of the Lyman schists. It is widest (3/4 mile) at the northeastern edge of the map, and can be traced thence for two miles southwestward, beyond which no exposures were seen. The rock is essentially a valley-maker, although it rises half-way up some of the adjacent hills, Fitch Hill being one of these (Sec. A, fig. 3). In the field the gneiss can be followed northeastward for more than a mile beyond the border of the map.

In passing across this belt, one finds that the rock gradually changes from a dark, hornblende-bearing, northern facies to a lighter, hornblende-free, southern facies. The petrology of these two phases will be described separately.

Northern phase.—In its northern outcrops the Fitch Hill granite gneiss is a fine-grained (average size of grain, 1/16 inch or less), dark gray or greenish gray rock, composed essentially of quartz, feldspar, and hornblende. The hornblende crystals are black, are more than twice as long as they are wide, and are without definite orientation. The feldspar is of a dirty pale greenish color. Sometimes a few very indistinct phenocrysts of this mineral are present, and rarely these are pinkish. The quartz is inconspicuous because its grains are small and transparent. Fine chlorite and sericite may be observed, particularly in those outcrops where there has been a little shearing.

In thin sections the microscope reveals evidence of crushing. The quartz, which is more or less granulated, has wavy extinction. Among the feldspars, orthoclase, microperthite, microcline, and plagioclase, ranging from albite to oligoclase, were

* Geology of Northern New England, p. 15. Geology of New Hampshire, vol. ii, p. 327, 1877.

† Ibid.

‡ New Studies in the Ammonoosuc District of New Hampshire, Bull. Geol. Soc. Am., xv, p. 465, 1904.

§ Ibid., p. 465. Also, by the same author, Geology of Littleton, p. 13.

|| Lambert, A. E.: In New Studies of the Ammonoosuc District of New Hampshire, p. 480.

¶ Geology of Littleton, p. 34.

recognized; but they are nearly always much decomposed. Epidote and sericite, disseminated through the decaying minerals, are most abundant as alteration products. A little calcite,

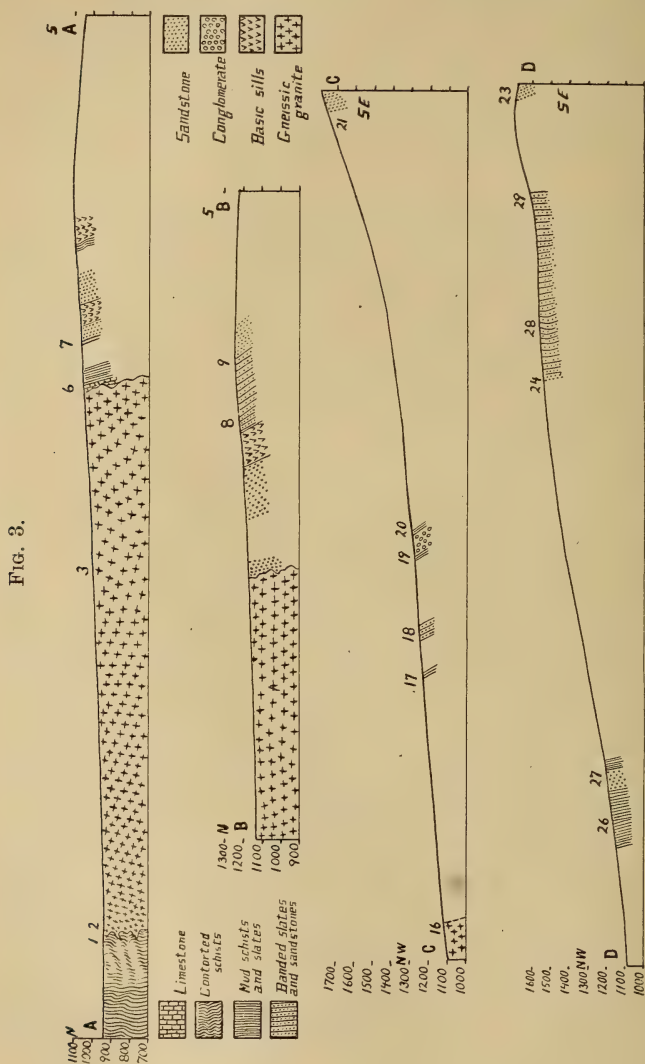


Fig. 3. Sections A-A, B-B, C-C, and D-D, the positions of which are indicated on the map (fig. 2). The horizontal scale is the same as that given in fig. 4.

which has crystallized between the grains of the rock, may have been derived from the lime-bearing feldspars. Having no sign of decay nor of distortion, and being moulded against or around the quartz and feldspar particles, the hornblende is

FIG. 4.

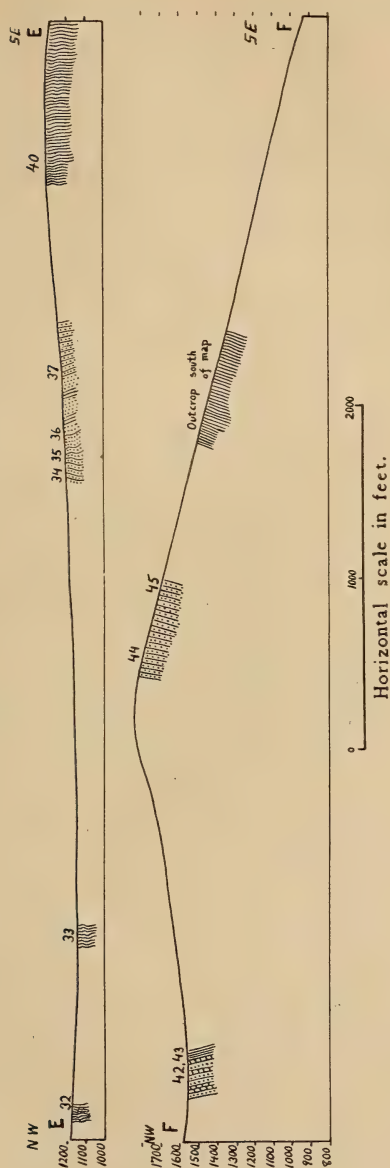


FIG. 4. Sections E-E and F-F. The legend for these sections is the same as that in fig. 3.

probably of metamorphic origin. It is often twinned in multiple fashion. The remains of decomposed biotite flakes ap-

pear as bent and twisted shreds of colorless micaceous material, associated with minute grains of quartz and epidote.

Southern phase.—The southern phase of the Fitch Hill granite gneiss is of rather coarse grain and is of a medium grayish tone, with light pink or flesh-colored crystals of feldspar. It is lighter in color and coarser than the northern type. Here, too, the quartz is not conspicuous. Frequently the structure is indistinctly porphyritic, and then the pink feldspars become phenocrysts with blurred edges. Many are twinned according to the Carlsbad law. Chlorite is always present, not as clear-cut individual flakes, but as irregular patches formed by many minute flakes. In some specimens chlorite occurs, together with sericite, as small, separate flakes, both micas being metamorphic in origin; and in such cases the chlorite is more abundant the greater has been the shearing. No hornblende was seen in the southern phase.

Many of the features observed in thin sections of the northern phase are characteristic of the southern. The quartz shows crushing and straining. The feldspars—orthoclase, microperthite, plagioclase, and a little microcline—are much altered. Of these the plagioclase preceded the others in time of development. Chlorite is in aggregates, accompanied by quartz, calcite, and epidote. Its form suggests derivation from biotite rather than from hornblende.

Variations in Mineral composition.—Five specimens of the gneiss were selected from as many different localities. Specimen 106 came from Loc. 10 (see fig. 2). Sp. 302 came from Loc. 5. Sp. 245 was taken from an outcrop not represented on the map. It belongs to the southern facies. Sp. 447 was obtained a few feet south of Loc. 2; and sp. 448, belonging to the northern phase, came from an outcrop northeast of Loc. 2, just off the map. Thin sections of these specimens were examined and the percentage of the constituents was estimated by thorough measurements according to the Rosiwal method.

To be sure, this kind of analysis, when applied to rocks of low metamorphism, and, therefore, of incomplete recrystallization, introduces errors which are large compared with chemical analysis; but it does bring out the relative abundance of the minerals clearly enough for general purposes.

The feldspars are not here classified by species. They are so much decayed that an attempt to distinguish them specifically, for quantity determinations, would be fruitless.

The results of the analysis are tabulated below:

	Per cent quartz.	Per cent feldspar.	Per cent calcite.	Per cent iron-bearing silicates.	Per cent total iron silicates.	Total.
Southern phase.						
Sp. 106	27.08	52.93	0	Chlorite : 19.97	19.97	99.98
Sp. 302	18.42	61.79	0	Chlorite : 19.59 Epidote : 0.18	19.77	99.98
Sp. 245	26.20	46.20	7.05	Chlorite : 20.54	20.54	99.99
Northern phase.						
Sp. 448	21.16	57.44	.36	Chlorite : 1.89 Epidote : 4.84 Hornblende: 14.30	21.03	99.99
Sp. 447	14.98	61.07	.17	Chlorite : 3.11 Epidote : 3.99 Hornblende: 16.66	23.76	99.98
Average for southern phase :						
	23.9	53.64	2.35	Chlorite : 20.02 Epidote : .06	20.09	99.98
Average for northern phase:						
	18.07	59.25	.26	Chlorite : 2.50 Epidote : 4.41 Hornblende: 15.48	22.39	99.97

The above table shows that the northern phase has a lower percentage of free quartz than the southern phase, a higher percentage of feldspar, and a slightly greater percentage of iron-bearing silicates, although hornblende comprises the larger proportion of these silicates in the northern type, and chlorite in the southern. Hornblende is quite wanting in the southern facies. These facts suggest a certain amount of magmatic differentiation in the original granite magma, either by an increase in acidity toward the southern boundary or by an increase in basicity toward the northern boundary.

Intrusive contact with the Lyman schists.—We can discover in the literature no mention of the relation of the Fitch Hill granite gneiss to the Lyman schists. Although the contact is actually exposed in many places, it is so obscure on account of metamorphism and weathering that its study requires more detailed search than was possible under the conditions of the earlier geological surveys.

When carefully examined, this contact is seen to be very irregular. The granite gneiss projects into the schists in the form of blunt apophyses or as short, narrow dikes. Most of these intrusive tongues are of fine grain; but a few are pegmatitic, sometimes with quartz and feldspar crystals an inch or two across. Angular fragments of the schist are occasionally seen entirely included within the gneiss. Add to these statements the fact that the gneiss usually grows finer toward the

schists, and there can be no doubt that this Fitch Hill granite gneiss is intrusive into, and therefore younger than, the Lyman schist group.

Unconformable contact with Blueberry Mountain Series.—At the southern contact the conditions are very different from those on the north. Here the gneiss rests against a body of sedimentary rocks which are much less metamorphosed than the Lyman schists. The lower members of this sedimentary series are known to be of Niagaran (Upper Silurian) age.* They were formerly called Helderbergian.

While the southern contact region does receive some mention in the geological literature, the references are vague. Lambert wrote that the granite gneiss "broke through" the sediments.† Hitchcock in one place‡ says it "cuts off" the "Helderberg." Elsewhere he says it "may be followed to close contact with the limestone" (Niagaran);§ and again, "Below and in contact with the fossils on Fitch Hill the rock is a chloritic foliated granite."|| On the same page|| we read, the "synclinal in Littleton rests on igneous materials"; and here, too, we find the suggestion of an unconformity in the words "basal limestones," meaning the Niagaran limestone.

We made as minute an examination of this contact as we did of the northern one. No dikes nor apophyses of any sort pass from the gneiss into the sediments, and, while the contact has several broad and often deep jogs or indentations, it is essentially straight. The granite gneiss sometimes remains coarse quite up to the sediments. More often, however, it grades into a somewhat finer rock. In one place where the gneiss adjoined this finer rock, the former seemed to pass into the latter by concentric layers about a roundish projection of fresh gneiss (see fig. 5). There were several such boulder-like masses of fresh gneiss partly or wholly wrapped in layers of the same material, more and more weathered outward. From these facts and from a microscopic inspection of the 'finer rock,' we have been led to infer that this contact is an unconformity; that the granite gneiss, preceding the deposition of the Niagaran, broke down, by disintegration without much decomposition, into a feldspathic gravel or coarse sand, now an arkose (the 'finer rock'); and that in some places we have the original spheroidal weathering preserved and bevelled across by the present land surface (fig. 4). Further support of

* See Hitchcock's *Geology of Littleton*, pp. 4-6, and his *New Studies in the Ammonoosuc District*, p. 462.

† Lambert, A. E.: A Trilobite from Littleton, etc., in Hitchcock's *Geology of Littleton*, p. 34.

‡ *Geology of Northern New England*, p. 15.

§ *Geology of Littleton*, p. 17.

|| *New Studies in the Ammonoosuc District*, p. 465.

these conclusions depends on certain characters of the overlying (to the south) Blueberry Mt. sediments, which we shall describe below.

Since the northern contact of the Fitch Hill granite gneiss is intrusive in its nature and the southern contact is an unconformity, (1) the original differentiation must have been one of increasing basicity toward the margin (northward), and (2) the age of this granite gneiss must be intermediate between that

FIG. 5.

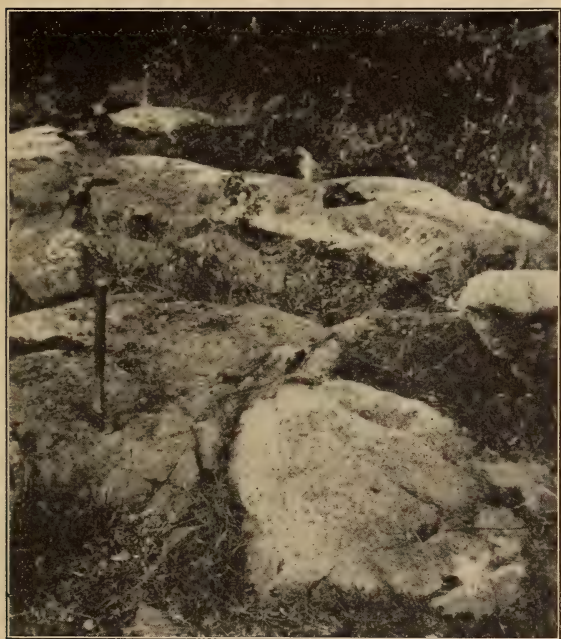


FIG. 5. Fossil concentric weathering. The rock in the right foreground is the Fitch Hill granite gneiss. It is partly surrounded by layers of the disintegrated gneiss, which have been reconsolidated since the time when the weathering was in process. The hammer stands on arkose which was formed from the completely disintegrated products of the gneiss. Photo by F. H. L.

of the Lyman schists and that of the Niagaran sediments on the south.

The Blueberry Mountain Series on Fitch Hill.—Blueberry Mt. is regarded as a synclinal ridge.* The base of the

* Hitchcock : Geology of Littleton, p. 15.

sedimentary series which forms the fold appears in the region above described, where the lower strata rest unconformably on the Fitch Hill granite gneiss. It is interesting to notice that Hitchcock mentions an unconformity on the southeastern side of the syncline about seven miles southwest of Fitch Hill, northwest of the town of Lisbon, where the Blueberry Mt. argillites meet the Swift Water series, a formation supposed to be equivalent to the Lyman schists and associated rocks on the northwest side of the syncline.*

In passing southward from the Fitch Hill granite gneiss, crossing the strikes of the strata, one encounters in succession (going upward, stratigraphically) (1) the basal arkose already mentioned, which may grade locally into quartzite beds (2–80 feet thick); (2) limestone carrying fossils of Niagaran age (30–40 feet); † (3) calcareous slate, also with fossils of Niagaran age (6–10 feet); (4) non-fossiliferous limestone and slate (150 feet)*; (5) basic sill (thickness uncertain; not great); (6) thick mass of arkose forming Fitch Hill and therefore called the Fitch Hill arkose to distinguish it from the basal arkose (200–300 feet); (7) basic sill (200 feet); (8) banded argillites (450–500 feet); (9) dark gray sandstone with dark shale layers (to the crest of Blueberry Mt.). ‡ The first four and the sixth members we have called the ‘basal series.’ Our measurements for the thickness of the basal series, exclusive of the sixth member, amounted to between 150 and 250 feet.

Further proof of the unconformity beneath these sediments is presented in the character of the basal arkose. This is a hard, compact, gritty rock, usually without the least indication of stratification. In one or two outcrops, however, a faint streaky appearance, striking and dipping parallel to the strata on the south, suggests that there was a very slight tendency toward sorting of the disintegration products of the granite gneiss in the encroaching Niagaran sea. The feldspar grains, ranging in size up to $3/16''$ or $1/4''$ in the longest dimension, are so conspicuous on account of their white color that they often give the arkose a porphyritic look. They are of the same kind as the feldspars in the Fitch Hill granite gneiss (orthoclase, microperthite, plagioclase, and some microcline). The quartz, together with a very little chlorite, constitutes a dark background for the feldspar. In thin sections the quartz is seen to be cracked and strained. Secondary calcite occurs as veinlets and fillings between the other minerals.

As a rule the feldspar in the basal arkose is nearly as abundant as the quartz; but in a few places the latter becomes rela-

* Hitchcock: *New Studies in the Ammonoosuc District*, p. 478, and fig. 8 on plate 42.

† Hitchcock's figures.

‡ Called ‘dark gray schists’ on the map.

tively so much more plentiful that the rock must be called a quartzite. It is then very hard and white. Ordinarily such quartzite beds are not more than five or six feet thick and do not extend more than twenty or thirty feet along the strike. They are purely local.

Above the quartzite or the arkose, as the case may be, and sometimes very near to the granite gneiss, is the limestone that carries fossils of Niagaran age. This limestone is of a bluish gray color and is crystalline. Since we found that it had certain peculiarities which marked it as different from other limestones with which we had been familiar, we studied it carefully. In an outcrop just east of the upper right corner of the map (fig. 2), two types of limestone were observed, one fine-grained and faintly banded and the other coarse-grained. These two kinds occurred as separate, pebble-like bunches, apparently lying in all attitudes (banding), and enclosed in a thin paste of fossiliferous calcareous shale. So small in quantity was the paste and so similar the colors of the two types that, with three or four exceptions, the outcrop as a whole seemed to be composed of uniform limestone. These exceptions were rounded pebbles of granite, contained, as the limestone 'bunches,' in the fossiliferous shaly paste. The granite of these pebbles looked strikingly like the Fitch Hill granite gneiss. Many of the limestone 'bunches' held crinoid stems, but no other fossils. In the shale paste, however, were numerous remains resembling *Stromatopora*, *Syringopora*, and *Favosites*.

On Fitch Hill, where Section A is drawn, the conglomeratic nature of the limestone is not so evident; but there are indications of it. In this connection it is interesting to note that there are occasional scattered, lenticular hollows, elongate parallel to the strike of the formation, in the basal arkose, even as much as ten feet below its upper limit. These little hollows (average: 8" long, 2" wide, 5" deep) are isolated pieces of limestone, weathered several inches below the surface of the outcrop. They are identical with the 'bunches' in the eastern outcrop just described.

Now, these observations, if correct, point to limestones of two geologic ages in the Ammonoosuc district. Indeed, our investigations in other parts of the region have led us to believe that some of the limestones hitherto mapped as "Mid-Upper Silurian"* contain crinoid stems, but no fossils distinctly of Niagaran age. This matter will bear more thorough study.

The fossiliferous slate (third member) is dark gray and calcareous. It has no particular importance for us, and will not be described at greater length.

Overlying this slate are the non-fossiliferous limestone and

* Hitchcock: *New Studies*, etc., plate 43.

shale beds, concealed for the most part by the vegetation. And stratigraphically above them is the second great mass of arkose, the 'Fitch Hill arkose.' Just what structural relations this rock has to those underlying, we cannot say. Contacts are not exposed. It appears to be in conformity. It is very like the basal arkose,—hard, dense, and spotted with white grains of feldspar which compose about half of the rock. It is more uniform in texture than the basal arkose, its grain averaging 1/15." No signs of bedding nor of limestone inclusions were seen. Microscopically, also, it is similar to the lower arkose.

Both of the sills are composed of a coarse, massive, unsheared rock, formerly consisting of hornblende and plagioclase. The hornblende has been replaced by zoisite, calcite, and chlorite. These intrusions grow much finer toward their upper and lower contacts. In spots they have metamorphosed the sediments.

The Fitch Hill arkose is overlain by a thick body of nicely banded mudstones or argillites. The bands, of lighter and darker gray, are from 1/2 inch to 3 inches wide, and may be traced for many yards. The lighter bands are fine argillaceous sandstone, and the darker, medium to fine-grained mudstone. They are very regular, but sometimes show local crumpling on a small scale. Neither this formation nor the overlying dark gray sandstone are of immediate concern for us. Their importance will be explained later.

Geology of the Blueberry Mountain Series Southwest of Fitch Hill.

Distribution.—We have previously stated that the Lyman schists pass off the map (fig. 2) and that the Fitch Hill granite gneiss narrows and finally disappears southwestward.

On the northern side of Fitch Hill the limestone is a valley-maker (not shown by the contours). Without entering into great detail of description, we may say that this limestone is thought to underlie the valley which is just northwest of Blueberry Mt., Bald Hill, and the hill in the extreme western corner of the map. This valley contains Young's Pond. Associated with the limestone are the other members of the basal series; but there are exceedingly few outcrops of these rocks. Locality 26 (sec. D, fig. 3) is an outcrop of coarse feldspathic grit resembling the Fitch Hill arkose. Half a mile southwest of this a large glacial boulder of conglomerate, with ten or twelve limestone pebbles in it, was found; and calcareous schist is exposed a few hundred feet away. Limestone and calcareous grits outcrop at Locs. 42 and 43. Here the lime-

stone is in thin, long lenses between thin calcareous shale layers. The limestone has been dissolved down several inches below the level of the shale (fig. 6).

The sills of Fitch Hill soon disappear and can be traced no farther.

The banded argillite of Locs. 8 and 9 cannot be definitely followed. A similar rock outcrops at 17 and 18, and also at Locs. 25, 28, 29, 30, 31, etc. Locs. 14 and 15 are dark gray slate. Locs. 19 and 20 are coarse conglomerate, traced 200 or 300 yards along the strike, but no farther.

FIG. 6.



FIG. 6. Differential weathering. The limestone layers have been dissolved out, leaving the argillaceous layers projecting as ridges. Photo by Mr. R. W. Sayles.

The banded argillites of Locs. 25 and 28 are easily followed southwestward in a belt which runs, parallel to the strikes, along the crest of Bald Hill, to the east of Young's Pond, and over the hill in the southwest portion of the map. In the northeastern localities this rock is like that in the Fitch Hill section, although perhaps a little coarser. It is similar, too, at Locs. 34-39. At 41, and to a more marked degree at 44 and 45, it is finer; and southwestward beyond the border of the map it becomes very fine. Accompanying this change of texture is also an increase in metamorphism. The more northern specimens are hard, but are scarcely sheared. Southwestward the content of secondary mica increases until, in the southwest, just off the map, the rock is a fine sericite schist or phyllite. The entire Blueberry Mt. series of sediments dis-

plays, although not always so obviously, the same southwestward advance in metamorphism.

Structure and correlation.—That Blueberry Mt. is thought to be synclinal in structure has been stated before. This conclusion is based, not so much upon an inverse succession of well-marked strata, as upon the exposure of pre-Niagaran rocks which are nearly identical on opposite flanks of the ridge. We are unable at present to locate the axial region of this fold. For some reasons it seems to be in or near the long belt of banded argillites. Dips (which have been omitted from the map) are usually steep, so steep, indeed, that variations in direction within the area mapped are probably due to local contortion rather than to actual synclinal or anticlinal folding on a small scale. Below are listed the dips for those localities where the attitude of the bedding could be obtained :

Locality	Dip	Locality	Dip
6	80° southward.	34	80° northward.
7	75° “	35	70° southward.
8	70° “	36	60° “
9	60° “	37	75° “
18	60° “	38	78° “
21	80° “	39	75° “
22	70° “	41	60° northward.
23	85° “	42	80° southward.
27	85° “	43	80° “
28	70° northward.	44	80° northward.
30	75° “	45	80° “
31	72° “		

As regards the relations of the Fitch Hill exposures of banded argillite, we cannot now say whether they are continuous with the outcrops at Locs. 17 and 18 or with the belt including Locs. 25 and 28. Various conjectures might be made. A fault might have caused an offset. Overlap might explain the increasing thickness of the Blueberry Mt. series southwestward. Or the exposures at 17 and 18 might be at the same horizon as those of 25 and 28, but on the opposite limb of a fold. This paper is not concerned with the full discussion of the geological structure of the region. We shall leave these matters to future investigators for settlement.

One significant point we do wish to emphasize, however. Cross-bedding in the sandstone of Loc. 22 and contemporaneous erosion at Loc. 27 show that relatively higher beds, stratigraphically, are in each case to the south, and that, consequently, all the strata from the valley up to Loc. 27 belong to the same limb of a fold.

Devonian fossiliferous horizon.—The sediments of Blueberry Mt. are less metamorphosed than anywhere else in the Ammonoosuc district. With this fact in mind, the writer was constantly on the lookout for fossils during his field work in this part of the country. In 1911 he chanced upon some poorly preserved brachiopod impressions in talus at the foot of the 'Craggs,' a precipice in the dark gray sandstone above the banded argillites south of Fitch Hill. The outcrop does not come within the bounds of the map. This is probably on the south side of the syncline.

The most important discovery was made last summer (August, 1912) at Loc. 25 (Sec. D). Here, in a layer of fine sandstone not more than two inches thick—one of the light gray layers of the banded argillites—were found fifty or sixty impressions representing eight or nine species of brachiopods and possibly one pelecypod. This harvest was so encouraging that careful search was made in the vicinity for more fossiliferous beds, but with no success. Even the one layer that contained these impressions was barren except within a length of about four feet. Subsequently, the banded argillites yielded more brachiopod remains at Loc. 39, near Young's Pond, almost three miles southwest of Loc. 25. Some very obscure impressions of the same nature were found at Loc. 21, on the crest of Blueberry Mt.

If, as we believe, the exposure at Loc. 25 is stratigraphically directly above the strata of Locs. 26 and 27, and if these latter rocks belong to the basal series, allowing for the slope of the hill and for the dip, the thickness of the beds between Locs. 26 and 25 is about 2900 feet.* It is unfortunate that the structure is so doubtful; but even if Loc. 25 were on the south limb of a fold, it would still be more than 3000 feet above the basal member on the south. This is demonstrated by the nearly vertical dips on the southeast slope of Blueberry Mt. We are forced to conclude, then, that these fossils come from a horizon many hundred feet higher than any of the fossiliferous beds hitherto known in the Ammonoosuc district.

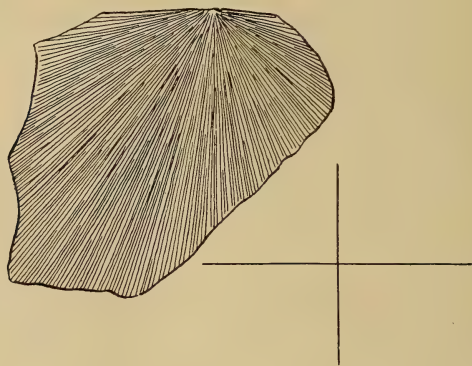
The layer containing the fossils is a hard, tough, medium gray, fine-grained sandstone in which a little secondary mica has developed, yet not enough to give the rock a cleavage. With a hand-lens it is seen to be pitted with small holes, probably the casts of some soluble mineral, such as calcite.

*In our notice printed in *Science* (N. S., xxxvi, p. 275, 1912), we said that the fossiliferous horizon of Loc. 25 was "stratigraphically 700' or more above the Fitch Hill" Niagaran limestone. This estimate was made before we had investigated the geology of the hillside below Loc. 25. It was obtained by adding the thickness of the basal series of Fitch Hill to the thickness of the banded argillites below Loc. 25. It was obviously very conservative.

Embedded in the sandstone, sometimes partly in a fossil and partly outside, are occasional large cubes of pyrite (up to 1/4" across). Most of the fossils are external impressions, although a few internal ones have been found. All of them are slightly distorted. (See figs. 7 to 9.) There is not a vestige of the original shell substance left.

While the characters of the impressions indicate eight or nine species, none of the fossils is perfect enough actually to determine its species. With the assistance of Professor Shimer, to whom we are glad to express our thanks, we made an attempt to name some of the genera. These are described below :

FIG. 7.

Fig. 7. *Stropheodonta* sp.?

(1) *Stropheodonta* sp.? (fig. 7): Only a part of one valve was found, including about 18^{mm} of the hinge-line. The impression is nearly flat. Its original size must have been at least 36^{mm} by 33^{mm}. It is marked by fine radial striae, all of equal height, of which 180 or 200 must have reached the outer margin of the shell when entire. Few run the whole length. These striae are crossed by still finer concentric wrinkles, or growth lines, which, however, are not well preserved. The hinge-line is straight and has on it indistinct vertical ridges. In general aspect this specimen is like *S. perplana*.

(2) *Chonetes* sp.? (fig. 8, actual size shown by cross): We have several incomplete specimens. The shell is about 20^{mm} wide and 12^{mm} long. It is nearly flat, slightly convex. Its surface is marked by fine, almost straight, equal, radial striae, about 100 in number. They are crossed by three or four low, indistinct concentric folds. The hinge-line is straight and forms the greatest diameter of the shell. Since the hinge area

is not well preserved in any specimen, we cannot tell whether or not spines were present.

(3) *Spirifer* sp.? (fig. 9). This is the most abundant species. We have portions of six brachial valves and of one pedicle valve. In no case were the two valves found together. The shell is 30 or 40^{mm} wide and 15 or 20^{mm} long. The brachial valve is characterized by a large unstriated median fold and, on each side of it, six or seven strong, rounded, radial plications that become narrower and lower near the hinge-line. There are no radial striæ. Very fine, thread-like, concentric

FIG. 8.

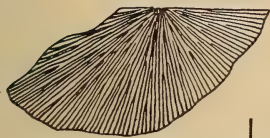
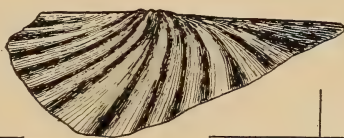
FIG. 8. *Chonetes* sp.?

FIG. 9.

FIG. 9. *Spirifer* sp.?

growth lines may be seen in some specimens. The hinge-line is straight and the beak is small.

The pedicle valve resembles the brachial valve except that it has a median sinus instead of a median fold.

Both valves are moderately convex.

(4) *Spirifer* sp.?: All the best specimens seem to be brachial valves. The impression is broadly convex. There are in all about twenty-four radial ribs, a dozen on each side of a rather inconspicuous median fold. No concentric growth lines are visible. The hinge-line is poorly preserved, but seems to have been straight. The beak is more prominent than in the preceding species.

There are several other species and genera among the specimens, but they are too fragmentary even for generic determination. One looks like a *Spirifer* of the type of *S. Murchisoni*. Another appears to be a *Spirifer* with very few and very distinct ribs. We shall postpone the description of these more doubtful forms until more satisfactory samples have been obtained.

The writer's examination of these fossils led him to believe that they were unmistakably of Devonian age. He, therefore, sent them to Dr. John M. Clarke, who kindly consented to look them over. In a letter to the author he wrote, "I should hesitate to identify any single species among these, though they are to me conclusively early Devonian."

In this fossiliferous horizon, then, we have evidence of marine deposition during early Devonian times. Unless the Fitch Hill arkose and the conglomerate of Locs. 19 and 20 represent a short cessation in deposition, sediments were being laid down continuously from Niagaran times up into the early Devonian, and this may have continued much longer. With the possible exception of a few hundred feet, post-Carboniferous erosion has removed all rocks higher than the Blueberry Mt. Devonian.

In the present connection we may quote the following remark of Professor Hitchcock: "The fossils characterize only the basal limestones,* which are middle Upper Silurian. There is certainly enough thickness of strata in the sandstone, slates, and conglomerate superposed on the limestones to suggest at least the residue of the Upper Silurian, and perhaps the Devonian."†

At Bernardston, Mass., in the Connecticut valley about 150 miles south of Littleton, is a section showing limestone overlain by quartzite. Fossils in these rocks prove them to be of Devonian age, the limestone Helderbergian and the quartzite Oriskanian.‡ Emerson assigns both limestone and quartzite to the Upper Devonian.§

The Littleton Devonian may be taken as additional evidence confirmatory of the Connecticut valley trough in which the marine Devonian strata of Bernardston have long been thought to have been deposited.

Institute of Technology, Boston.

* On Fitch Hill.

† New Studies in the Ammonoosuc District, p. 465.

‡ Clarke, J. M.: Early Devonian History of New York and Eastern North America. N. Y. State Museum, Memoir 9, vol. 1, p. 156, 1908-1909.

§ Emerson, B. K.: Geology of Old Hampshire County, Mass., U. S. G. S., Monog. xxix, p. 258, 1898.

ART. XXVI.—*The Liassic Flora of the Mixteca Alta of Mexico,—Its Composition, Age, and Source*,* by G. R. WIELAND.

DURING the year 1909 the writer enjoyed the permission of the Carnegie Institution of Washington to make, in conjunction with the Instituto Geológico of Mexico, a long projected reconnaissance in search of fossil cycads in southern Mexico. But inasmuch as the publication by the Instituto Geológico of the results later brought together in the form of a considerable memoir in quarto illustrated by text figures and fifty excellent plates, under the title *La Flora Liásica de la Mixteca Alta*, (Boletín No. 31), promises to proceed slowly, a supplementary abstract in English indicating the scope of the field and laboratory work accomplished has the sanction of Director Villerello and seems doubly desirable. The more is this the case because the southern Mexican plant beds prove to begin with the lower Lias and thus represent the first typical Liassic series to be described from North America. Not only so, but the Williamsonian cycads yielded in unsurpassed abundance throughout the great thicknesses of strata measured must be ranked geographically as one of the most interesting Mesozoic cycad floras of the globe. That results of first importance were obtained has already been pointed out in a brief paper in the Botanical Gazette for December, 1909; although in that contribution the facts considered were mainly biologic.

Since not only the paleobotany of the great plant beds of Oaxaca but all present views of their age and structure must undergo extensions and revisions involving many years of work, the use of a somewhat general regional name in the title of the present purely initial study has seemed most appropriate. That chosen is a semi-geographic, semi-ethnologic one first called to my attention by Sr. Gonzales of the Instituto Geológico. The "Mixteca Alta" or upper country of the Mixtecas is only a more or less indefinite portion of the plateau and mountain region of Oaxaca and adjoining states occupied by the original Mixtecan tribes. The name is used for the "Tierra templada y fria" in contradistinction to the "Mixteca baja" or lower country of the "Tierra caliente" over which these tribes extended. Conveniently speaking, then, the Mixteca Alta is a portion of the southern border region of the Cor-

* The present article is properly a continuation of the series of preliminary Studies of American Fossil Cycads brought out in this Journal under the auspices of the Carnegie Institution of Washington. These studies now include: Parts I-III which appeared serially in March-May 1899,—Part IV, June 1901,—Part V, August 1911,—Part VI, February 1912; together with additional papers on the Proembryo of the Bennettitæ, December 1904,—Historic Fossil Cycads, February 1908, and the contribution on the Williamsonian Tribe of December 1911.

dillieran system, facing the Pacific and extending through central and western Oaxaca well into Guerrero as well as northerly into Puebla. Nor is it in the main a markedly elevated portion of the so-called high plateau region of Mexico, for to the north lie the lofty peaks about Puebla, and to the southeast the great Sierra Juarez mountain knot, the latter resting almost directly on the Cordilleran front. In fact the upper Mixtecan region in which the Jurassic plant beds are a great geologic feature is in part only a moderately elevated but much folded and faulted basin. Or at least there are border or transverse ranges which have partially protected both the marine and underlying freshwater deposits from the full effects of dissection and erosion and all those tremendous tectonics to which the superbly beautiful and picturesque Mixteca Alta region has long been subjected.

The ten or twelve thousand feet of Mesozoic strata which give character to the Mixteca Alta are about equally divided between the Jura and Cretaceous, any Trias that may occur not being as yet distinctly classified. The Mesozoic mass is often entirely freed from Tertiary eruptives, ash or conglomerates, and rests on older sedimentaries of undetermined age, or against intrusives. The topography is exceedingly rough. The streams in cutting through the massive Cretaceous limestones capping Jurassic strata of lesser induration form a tremendous system of deeply cut valleys, gorges, and cañons. Yet because of the distinctly varied vegetation and rather free growth of pine and oak with relatively few barren stretches, scenic aspects are far softer than in the upland mountain country of central Mexico.

The general physiography is especially well developed along the valley of the Tlaxiaco river, and the adjoining photograph of this valley as seen from a point about eight kilometers westerly from the town of Tlaxiaco conveys a clear idea of scenery in the uplands of the Mixteca Alta. The view is from the right, the course of the valley northerly, and to reach the river bed some 300 meters lower, the "trail" here makes a long detour. Just over the pack train a long steep side valley is plainly seen to lead down into the main valley just to the right of the frontal mountain mass of Jura-Cretaceous strata. And where this lateral valley debouches a thick series of Liassic sandstones and shales bearing thin seams of coal is cut into for some distance along the river bank. In fact here are a number of coal prospects; but unfortunately the dumps were located directly on the river bank, and had been nearly all washed away during the rainy season preceding my visit. So that in the absence of fresh excavation or new quarries, there were recovered at this particular point but a very few of the rich store of fossil cycads unquestionably present.

FIG. 1.

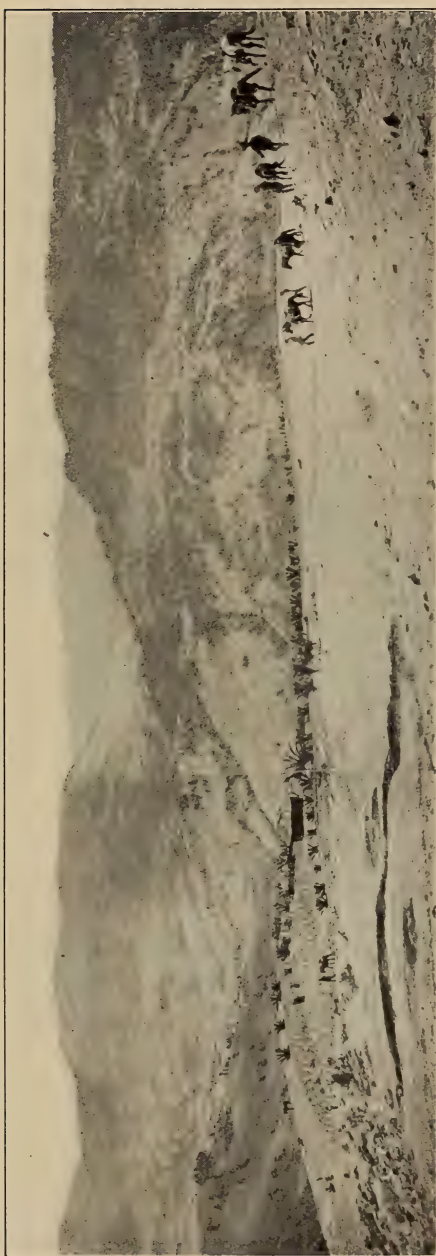


FIG. 1. Valley of the Tlaxiaco River.

A.—Localities and Geologic Sections.

The material on which is based the longer memoir on the Liassic Flora of the Mixteca Alta mentioned above was all personally collected by the writer during the spring and early summer of 1909. The chief localities yielding fossil plants in abundance and at which collections were made are:—

1. On the Tlaxiaco river to the westward of the town of Tlaxiaco at prospects of the Oaxaca Iron and Coal Company. Cf. fig. 1.
2. In the hills three to five kilometers northwesterly from Tlaxiaco.
3. At Mixtepec on the Rio Mixtepec, where considerable prospecting for coal has been carried on.
4. About and to the east of the Cerro del Lucero in the Tezoatlan and Rosario region.
5. On the Barranca Consuelo between the Cerro del Lucero and Cerro de Venado. Here a magnificently exposed section permitted the location of various quarries and the accurate measurement of plant beds reaching nearly six hundred meters in thickness. In addition the prospects of the Oaxaca Iron and Coal Company, where some coal is actually mined, made possible collections from the lower third of the section which could hardly have been had from the surface quarries alone.

The plant occurrences in the Barranca Consuelo are so many and striking that in this preliminary notice the material from the other localities only needs to be considered in a minor or supplementary way.

But it should be recorded that in a hasty visit to the valley of the Nochixtlan river at a point to the southeast of Chalco-tongo, Sr. Bonillas of the Instituto Geologico observed in the spring of 1909 a heavy development of plant-bearing beds fully four hundred meters in thickness. And from his account and my own observations made later along the Yaqui River valley in Sonora I suspect that here is a true Triassic extension of the Barranca Consuelo section. Moreover in the following year Sr. Bonillas had the fortune to find *Williamsonia* flowers near Tlapa in the State of Guerrero in sandstones of a somewhat light-colored to vitreous appearance recalling very sharply the characters of some of the cycad-bearing rock of the Rajmahal series as first reported by Oldham and Morris.

The first observation of fossil cycads in southern Mexico was doubtless made by Señor Aguilera, formerly director of the Instituto Geológico, who not only visited the Barranca Consuelo some thirty-five years ago, but also noted what must have been *Williamsonia* disks near the prominence called the "Pina de Ayquila" near the village of Ayquililla in the

State of Puebla. But very unfortunately the material gathered on this early reconnaissance was later lost when a vessel on which it was being conveyed by Señor Aguilera to Washington for comparison and study was burned in the Havana harbor. Also a fossil cycad from the Puebla-Oaxaca country named by Ward in the 8th report of the U. S. G. S., but not figured, has been lost to view; while Felix and Lenk in their pathbreaking work in Oaxaca did not have the fortune to find the rich cycad-yielding terranes on their visit to the Tlaxiaco country. Very little, therefore, has been known of either the extent or character of the cycad flora of southern Mexico previous to the present studies, clearly the first devoted to the subject.

The characteristic plants of the Mixteca Alta Lias are probably more or less abundant at all the localities mentioned. And all will richly repay far more thorough prospecting than I was able to give them, unless with the partial exception of the Barranca Consuelo section, to which I mainly confined my efforts to make a fairly complete collection. But even there, the perfected field methods of the future may not impossibly involve the establishment of quarries in horizon after horizon following persistent trenching, with a resultant yield of fossil plants such as may make the collections I was able to bring together look small and insignificant in both conservation and number. The fact that the plants are often carbonized and that beautiful casts occur as well as silicified logs, must always give to the section a high interest to collectors.

In the initial studies it proved not only convenient, as just indicated, but desirable to devote close attention to the typical section on the Barranca Consuelo; for it was at once seen that the strata of the plant beds could there be measured almost meter by meter for the full five hundred and fifty meters in thickness, while in passing down the *barranca* the series reappears from beneath the superposed Jurassic and Cretaceous in the reverse order. However, the detailed remeasurement thus permitted was not made, this left over work being only one of the refinements of the study of this section which cannot fail to yield results of deep interest and value.

Not only so, but in all the region where the sedimentaries come to the surface there are many points where new quarries can be opened without difficulty. This must be particularly true to the northeast of El Cerro del Lucero along the Rosario ridge, to say nothing of a score of general localities I did not find time to seek out or examine. Indeed, because of the present flora and the exquisite climate as well as the geologic structure, one cannot but regard the Mixteca Alta as being one of the most promising and attractive regions of the globe for the collector of fossil plants. And I have had occasion to speak of this extreme attractiveness to the student of cycads

at some length in my above mentioned first contribution on the *Williamsonias* of the Mixteca Alta; though unhappily the revolutions of the past few years have rendered exploration unsafe, and thus far prevented a resumption of the work I much wished to make.

Moreover, it should be especially emphasized that the Liassic plant beds form only about a third of the entire thickness of freshwater and marine Mesozoic so sharply cut through on the Barranca Consuelo. The superposed Jurassic and Cretaceous strata aggregating a mile in thickness may also be measured with an approach to the accuracy permitted by the exposures in a quarry. Omitting however any measurements of superposed beds, we may now give the preliminary measurements of the plant beds with brief field notes. Though I should add that the full Mesozoic section of the Barranca Consuelo series was subsequently remeasured conjointly with Señor Bonillas, then engaged in geologic mapping of the Tezoatlan-Tlaxiaco region, the utmost care being taken to not only make all measurements exact, but bring the elements of the section into briefer form for cartographic purposes. The second measurements in actuality vary but little from those which here follow as being of the greater present interest because made from the immediate viewpoint of the collector of fossil plants. But the plant beds are the only portion of the Consuelo section with which it is practical to now concern ourselves. Furthermore the extended section is given in the completed memoir.

Given just as jotted down in the field the measurements which follow must prove an aid to future collectors who will not fail to revisit and restudy this most important type section for the North American Lias. For I urge alike the necessity of keeping the records of subsequent collections clear, and the richness and promise of this great section. To an inexperienced collector it might appear barren, though after patient examination the richness of the record conserved will never fail to excite even wonder. How the great collections here certain to be made will finally appear no one may venture to guess; though many questions already rise to mind. To say nothing of the absence of the conifers so far, it is for instance even more singular that of all that remarkable group of net-veined *lyre-ferns* of the *Dictyophyllum-Clathropteris* series so strongly characterizing the Rhätic of Tonkin, and still in part persistent in the European Jura, not a trace has yet been found here. Bar contrary testimony from the field the explanation nearest at hand is of course that the Tonkin flora not only marks a time of dominance for these net-veined types of *pre-Angiosperm* time but that they indicate a tropic climate more constantly moist than was that of the Oaxacan Lias, which was probably of the Monsoon forest type favoring a more distinctly xerophyllous vegetation.

PRELIMINARY RECORD AND MEASUREMENT OF THE SECCION
CONSUELO.A. *The Plant Beds.*†

(Fossil Plant-bearing strata are indicated by a *.)

0. Eruptive floor and intrusives. Ends at and produces two small gullies running directly up from both sides of barranca. Dip of floor is 30° , which is similar to that of the overlying sedimentaries.
1. First member of the sedimentaries. Forms the west slope of the above gullies as result of erosion. Clayey shaly bed too soft to form sharp ledges. Covered by grassy growth in distinct contrast to the eruptive floor, which is usually rather barren. Fossils probably present, but not appearing at the surface... M. 30
2. Shales and sandstone strata, with much checked, iron-stained and clayey nodular masses quite similar to those yielding *Williamsonia* casts abundantly some 50 meters further up in the section. There is distinct shaly lamination, and sufficiently deep excavation would probably reveal fossil plants..... M. 46
- 3.* Indurated and laminated clayey or shaly rock which forms sharp ledges in the bed of the barranca. Except in a few feet of the lower portion but little softer material. Meagerly fossiliferous..... M. 15 ±
- 4.* Another soft but distinctly laminated bed with some thin sandy layers. Probably fossiliferous M. 17
5. Sandy and clayey to indurated strata, forming ledges and ending in a horizon with thin seams of coal..... M. 24
6. Contains considerable carbonaceous material interpolated in clayey and sandy strata. [Dip suddenly increases to 60° .] (Fault of possibly 10 meters not accounted)..... M. 18
- 7.* Sandstone coal and shale. The record of the "A shaft" of Oaxaca Iron and Coal Company includes this horizon as follows, measuring from above downward:—" [25 feet of surface wash]; carbonaceous shale, 6 feet; coal with clay 'horses,' $2\frac{3}{4}$ feet; carbonaceous shale, 3 feet; hard calcareous or argillaceous or marly shale, $2\frac{1}{2}$ feet; coal with 'horses,' $1\frac{3}{4}$ feet; calcareous shale, $2\frac{3}{8}$ feet; coal, $\frac{3}{4}$ foot; carbonaceous shale, 3 feet; calcareous shales with interpolated carbonaceous or coaly layers, 15 feet." Total..... M. 19

The strata of No. 7 are very rich in fossils. *Negerathiopsis* and *Alethopteris* with *Otozamites Mandelslohi*, and the *Otozamites Molinianus* series, were all derived from this horizon. *Teniopteris*, so remarkably abundant in the Yaqui river Trias of Sonora, and in the valley of the Nochixtlan river, is here curiously scarce.

† Various references to plates of the memoir later to appear in Spanish are retained.

8. More or less lenticular grits followed by sandy and clayey strata M. 53
- [Note.—The numbers 1–18 were at first assigned to the preceding 1 to 8; but as the outcrops of these strata on the barranca yielded few fossils the lesser divisions were soon dropped. The next numeral 19 is therefore arbitrarily made to follow No. 8.]
- 19*. Yellow much checked ferruginous and arenaceous shales sometimes slightly conglomeratic. Uppermost portion rich in fossil plants. A small quarry established on the right bank of the barranca immediately opposite a large “ahuehete” (*Taxodium mucronatum*) yielded the *Otozamites hespera* of Plate VIII. Dip 50°. M. 60
20. Easily eroded argillaceous and sandy material not forming surface ledges or outcrops along the barranca. M. 25
21. A distinctly gritty to conglomeratic stratum M. 1
22. Argillaceous sandstones M. 2
23. Small pebble, but well-marked conglomerate M. 2·5
24. Light or slightly chocolate-colored sandy shale..... M. 2
25. Sandy, gritty to conglomeratic layer M. 4
26. Clayey, ferruginous shale much like No. 24, markedly concretionary below M. 2·5
- 27.* Gritty sandstone with indistinct remains of plants... M. 1
28. Repetition of Nos. 24 and 26 M. 1
- 29.* A repetition of No. 27 with grits below succeeded by finer materials above containing *Ptilophyllum* or *Williamsonia pecten* fronds..... M. 2
- 30.* A soft sandstone corresponding to Nos. 24, 28, with some fossils M. 2
31. Stratum gritty below to smooth above. Sandy. A repetition of Nos. 27 and 29 M. 1
- 32.* Sandy material with numerous *Ptilophyllums* in middle portion. [No quarry was opened here, although one should be made] M. 3
- 33.* Gritty clays and sands with some plants above M. 2
34. Shales repeating the characters of Nos. 24, 26, 28, and 30 M. 3·5
35. Gritty below and shading into finer sandstone above, precisely as in No. 33; but no plants noted M. 2
36. Shale without hard ledges continuing up to another layer of grit M. 16
37. Sandstone with more or less flow and plunge structure, although clays are also interpolated. Apparently combines the same kind of materials that are more distinctly separated into the lesser strata numbered 26, 28, 30 and 27, 29, 31 M. 16
38. Sandy to clayey horizon, straticulate to nodular, and not varying sharply from No. 37..... M. 3
39. Gritty to conglomeratic stratum, harder and more quartzose than the preceding M. 1

40. A fine-grained sandstone M. 2
41. Argillaceous to arenaceous bed without ledges M. 16
- 42.* Sandstones, with frequent gradations into shaly and concretionary structure. Thin carbonaceous bands are present. Many plants above. The large-leaved *Williamsonias* and large buds, stems and *Cycadolepis* are first met with in this important horizon. [Cf. Plates XXI-XXVI] M. 19
- 43.* More or less straticulate sandy and shaly layers with plants. [The *Ptilophyllums* occur here in great number. Cf. Plate I, etc.] M. 3
44. Somewhat gritty sandstone M. 2
- 45.* Nodular shales, with more or less imperfectly conserved plants M. 2
46. Arenaceous shales or clays without sharp ledges M. 5
47. Gritty to conglomeratic ledge stretching across bed of barranca M. 2
- 48.* Arenaceous shales not forming sharp ledges. Many cycads below. Mostly the smaller *Ptilophyllum*. Cf. Plate VII. M. 18
- 49.* Shales with slightly straticulate zones not forming sharp ledges. Plants indistinct M. 4
- 50.* Gritty to slightly conglomeratic material softer above and probably bearing good plants in some situations. . M. 2
- 51.* Sandstone ledge with indistinct imprints of logs in lower portion M. 5·5
- 52.* Straticulate arenaceous shales ending in a more argillaceous layer with well-conserved plants M. 13
- 53.* Sandy lenses and arenaceous shales with thin bands of shale containing plants. Carbonaceous seams near middle, but no coal and no distinct ledges M. 21
- 54.* Arenaceous and clayey materials with a well-defined clay stratum and finely conserved plants near middle. Forms a ledge on left bank of barranca only, the right bank being quite smooth M. 8
55. Alternate bands of shaly and arenaceous materials, some carbonaceous shale below but no distinct plants. M. 14·5
56. Sandstone containing one shale stratum one third of a meter thick, and ending in nodular to straticulate sandrock M. 3·5
57. Grits, conglomerates, or sandstones mostly fine-grained and massive with little argillaceous lamination. Sometimes the sandstones show flow and plunge structure. In upper portions indistinct stems of plants. This series forms a prominent ridge M. 29
58. Soft sandstones not forming ledges. Produces surface soil nearly free from clay M. 17
59. Sandstones, more or less micaceous to clayey and laminated above M. 3·5

- 60* Shales ending in micaceous sandstone with well-conserved cycads above. An important horizon, and the highest from which good fossil plants were secured. . . M. 6.5
61. A hard conglomerate ledge with a dip of 60°, quartzitic below and forming a waterfall. Notable feature of the barranca. (Cf. upper right phot., Pl. XLVIII.) M. 12.5
62. Soft shaly or sandy materials ending above in several two-meter thick ledges of quartzitic sandrock. M. 20
 Note.—The dip here sinks from 60° to 45° with a slight change in strike from nearly N. to about N. 10° W.
63. Shaly ferruginous layers without hard ledges. [Brachiopods (undetermined) in Yuququimi trail.] M. 23
- 64.* Dark and compact quartzite containing some good pinules of cycads. (Difficult to break out the fossils, and no collections made or studied.) M. 1
- 65.* Shales often bluish in tint, nodular and ferruginous. Plant remains very indistinct. M. 16.5
66. Sandrock, massive below, but straticulate above, with some clayey seams. Forms prominent ledge on both banks of barranca. Contains poorly conserved remains of large stems of trees. M. 9
67. Shales somewhat nodular below, but not above. Easily eroded, and because followed by hard shell rocks and limestones above, responsible for sharp turn of barranca at a right angle. [The course of the barranca follows this soft horizon for about 200 meters and then breaks through the harder rocks above along the course of a small fault with a throw of about a meter or less.] Marine Liassic-Oölitic superposition. M. 5

Principal Totals.

Meters.

1. Entire thickness of the plant beds by the preliminary measurements with allowances for lesser faults, <i>M. 600</i> , the corrected total being	567
2. Height of horizon of the <i>Williamsonia Nathorstii</i> casts above eruptive floor	85
3. Height from eruptive base to the principal coal seam horizon with <i>Næggerathiopsis</i> , <i>Otozamites Mandelslohi</i> and other broad short-leaved <i>Otozamitans</i> with <i>Alethopterids</i> , etc.	100
4. Base of plant beds up to <i>Otozamites hespera</i> zone and approximate horizon of silicified <i>Araucarioxylon</i> log. . .	240
5. Approximate thickness of lower plant beds	250
6. Base to the main <i>Williamsonia</i> horizon	350
* * * * *	

The interpretation of the foregoing measurements is in the light of the plant occurrences entirely simple. It is obvious that coincident with land emergence there was a more or less

differentiated series of oscillatory subsidences, which increased to a maximum at the time of the deposition of the quartzose conglomerate No. 61. Meantime, the subsidences, followed locally by conditions of moderately quiet waters with shore distance and depth suitable to the deposition of plants in fine muds, were very frequent. They were marked by the laying down of abundant plant remains and where pronounced of coal.* With the later sharp encroachment of the oölitic seas following the deep water bed No. 67 the formation of shell limestones with alternate marine or semi-marine sandstones begins, while later still, the deep Jurassic and Cretaceous oceans entirely transgressed the plant bed region.

That the history of the plant beds consists in a single unit is not believed; even if relatively short, there may have been three, if not four, series of events involved in their deposition. But it seems much the more scientific method to avoid hasty and perforce arbitrary methods of division, whether resting the case on either the plant or the physical record as now known. And it must be far preferable to use, for the time being, the purely tentative demarcation into lower and upper beds and await the accumulation of exact evidence as to the actual course of deposition and floral change.

B. Composition, Age, and Source of the Mixteca Alta Flora.

In further comparing representative Jurassic floræ like those of Italy, Bornholm, Yorkshire, India, and California, it seems that the age usually assigned to the plants of these several regions is in the main correct. That is to say, however uncertain in their application, however illy defined and variant may be the methods for determining the succession of the earlier Mesozoic floræ, the general mode of procedure is at least fairly enough understood and agreed upon to yield approximations to the true age.

But aside from exigencies of fossilization, climatic variations, and rates of migration or dispersal, all comparisons of

* Neither the position nor local trend of the land masses which furnished the fossil plants of the Consuelo section has been worked out. The plant beds may indeed lie near to a long, approximately east-west shore line. But, in any event, there is much doubt if the coal seams, always or ever, indicate swamp bottoms. The comminuted condition of much of the plant material of the coal seams may as well indicate flotation of rafts into deeper waters as swamp bottom conditions; while the fine clays, which are so generally intermingled and alternate so often, may mostly be the result of sedimentation in deeper waters.

Fortunately, we may presently expect some direct information as to the nature of these coals, the Instituto Geológico having, through the courtesy of the director, Señor Villerello, arranged to send a complete series of the Mexican coals to Professor Jeffrey of Harvard for study by the highly effective methods of thin sectioning he has developed.

such widely separated floræ as those cited are doubtless further obscured by the fact that any given flora may be old or young for the region in which it occurs. A plant facies may be either juvenile or senile. Thus, as will be further cited below, it is strongly suspected that the plants of the Inferior Oölite of the Yorkshire Coast are old, are really a left-over Liassic

FIG. 2.

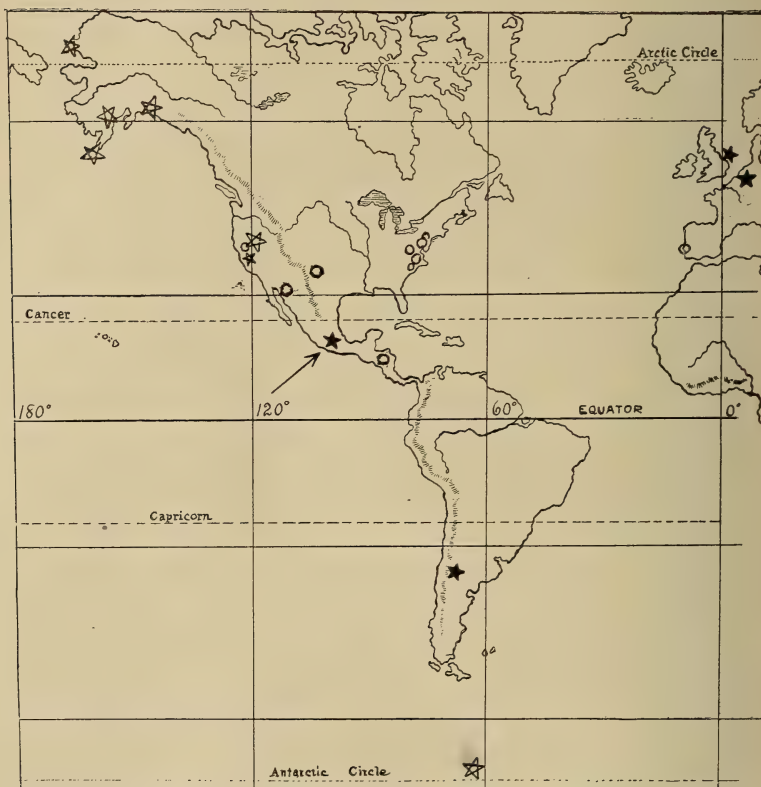


FIG. 2. Principal Triassic and Jurassic plant localities of Western Europe and the extra-arctic Americas. [Disks] denote *early*, and circles *later* Trias, solid black stars, *early*, and outline stars *later* Jura. The arrow points out the newly discovered Mixteca Alta horizons of Mexico, where 600 meters of Liassic strata have been measured and true Triassic plants are also believed to occur. These plant beds are widely extended over the region stretching westwardly from the valley of the Nochixtlan river in Oaxaca to Tlapa in the state of Guerrero (or further), and northwardly into southern Puebla.

rather than a typical mid-Jurassic facies. For these plants may readily have been existent during the deposition of the

underlying "Midford sands." These contain, at their top, the famous Gloucestershire "Cephalopoda beds," and do not yield fossil plants. Furthermore, they are recognized as transition beds, and sometimes actually assigned to the Lias.

Contrariwise, as will presently appear, the more critical comparison of the Rajmahal Hills flora with that of Oaxaca indicates the latter to be essentially juvenile, there being distinct reason to believe that as the study of this prolific region for fossil plants goes on, evidence is likely to increase that the plants in the lower portion of the beds were fossilized soon after their incursion from the North or South, or soon following the rapid local development of new species. At least, taking the Mesozoic as a period of marked changes in plant facies, there must be a certain significance in the persistence amongst the Oaxacan plants of certain old elements, which in longer established floræ might be mostly eliminated.

Admittedly, however, the conclusion here reached can only have a tentative value, since in the absence of inherent evidence of geologic age such as many types of Jurassic plants fail to reveal in the present state of our knowledge, it may even prove uncertain whether given groups of plants which appear most alike, are of the same age or not. All that can be done safely is to surmise or approximate. For not only are the chances in all cases very great, that any two such widely separated floræ are not exactly synchronous; but however strong their resemblance, there is this ever-present possibility that one is old and long established, the other young or recently established, and undergoing change. The lack of various old types in the first case and their retention in the second would, of course, give a clear result if we knew the Jurassic plant succession better. In general it seems clear that the pulsations or waves of plant evolution marking successive epochs must have had their dawn, their high noon, and their eventide, and that extinction, in any period, must also have had its initial, maximum, and minimum phases; though it is even clearer that, locally, the problems of plant age and dispersion soon pass beyond the known facts of homotaxy, and that they involve factors of the utmost difficulty.

But without further outlining these obviously severe limitations to accuracy in assigning the age of fossil plants, it will be most convenient, as a prelude to such discussion of the age and source of the Oaxacan plants as can be given, to first range the species alongside their nearest old world counterparts, as is done in the appended Table I.

TABLE I.—Recapitulatory Table of the *Mixteca Alta* Flora showing Relationships to the most nearly allied previously known Floræ.

MIXTECA ALTA SPECIES.	RECURRENT SPECIES.	AFFILIATED FORMS.
<i>Anomozamites Lindleyanus</i> var.	-----	<i>Anomozamites Lindleyanus</i> , Lias : Europe, and Sripematur.
<i>Cycadeospermum oaxacensis</i>	-----	<i>Cycadeospermum</i> [or <i>Cycadospadix</i>] : Liassic on.
<i>Cycadolepis mexicana</i>	-----	<i>Cycadolepis</i> , Lias : India, etc.
<i>Otozamites cardiopteroides</i>	-----	? <i>Otozamites Beani</i> Brongn., Yorkshire.
<i>Otozamites hespera</i> .		
<i>Otozamites hespera</i> var. <i>intermedius</i> .		
<i>Otozamites hespera</i> var. <i>latifolius</i> .		
<i>Otozamites paratypus</i> .		
" <i>Mandelslohi</i>	<i>Otozamites Mandelslohi</i> , Lias : Continental Europe.	
<i>Otozamites Molinianus</i> var. <i>oaxacense</i>	-----	<i>Otozamites Molinianus</i> , Lias : Southern Europe and Bornholm.
<i>Otozamites obtusus</i> L. & H.	-----	<i>Otozamites obtusus</i> (Lias of Yorkshire).
<i>Otozamites</i> n. var. <i>Liasicus</i>	-----	<i>Otozamites obtusus</i> var. <i>Oöliticus</i> , Lias : Yorkshire.
<i>Otozamites</i> n. var. <i>oaxacense</i>	-----	
<i>Otozamites Reglei</i> n. var. <i>lucerensis</i>	-----	(a) <i>Otozamites Reglei</i> European Lias.
<i>Otozamites</i> (<i>Otopteris</i>) sp.		(b) <i>Otozamites Hislopi</i> , Jabalpur group.
<i>Otozamites</i> (<i>Williamsonia</i>) <i>Aguilariana</i> ..	-----	(c) <i>Otozamites terquemi</i> (infra-Lias).
<i>Otozamites</i> (<i>Williamsonia</i>) <i>Aguilarii</i> .		<i>Williamsonia gigas</i> , Yorkshire coast and Continental Europe ; Oölite or older.
<i>Otozamites</i> (<i>Williamsonia</i>) <i>Diazii</i> .		
<i>Otozamites</i> (<i>Williamsonia</i>) <i>Juarezii</i> .		
<i>Otozamites</i> (<i>Williamsonia</i>) <i>oaxacensis</i> .		
<i>Otozamites</i> (<i>Williamsonia</i>) <i>tribulosus</i> .		
<i>Pterophyllum</i> cf. <i>contiguum</i>		<i>Pterophyllum contiguum</i> , Rhätic, Europe.
<i>Pterophyllum Münsteri</i>	<i>Pterophyllum Münsteri</i> , Rhätic, Continental Europe	<i>Pterophyllum Münsteri</i> , Rhätic of Tonkin.
<i>Pterozamites</i> (<i>Pterophyllum</i>) <i>angustifolia</i>	<i>Pterozamites angustifolium</i> [Early Jurassic].	

TABLE I—(Continued).

MIXTECA ALTA SPECIES.	RECURRENT SPECIES.	AFFILIATED FORMS.
<i>Ptilophyllum acutifolium</i> cf. var. <i>maximum</i>	-----	<i>Ptilophyllum acutifolium</i> var. <i>maximum</i> , Gondwanas of India.
<i>Ptilophyllum acutifolium</i> nov. var. <i>minor</i>	-----	<i>Ptilophyllum</i> or <i>Williamsonia pecten</i> , Yorkshire Oölite and Gondwanas of India.
<i>Ptilophyllum pulcherrima</i>	-----	<i>Ptilophyllum</i> forms of India.
<i>Stangerites oaxacense</i>	-----	<i>Stangerites McClellandi</i> , Upper Gondwanas and in European Lias S. Haidingeri.
<i>Williamsonia</i> [fruit series]	-----	<i>Williamsonia</i> , Yorkshire Oölite fruit series.
<i>Williamsonia</i> [stem series]	-----	<i>Williamsonia</i> , Upper Gondwana stem series.
<i>Williamsonia mexicana</i>	-----	<i>Williamsonia whitbyensis</i> , Yorkshire Oölite.
<i>Williamsonia Nathorstii</i>	-----	<i>Podocarya</i> ovulate cone of Buckland, Lias of Lyme Regis.
<i>Zamites</i> cf. <i>confusus</i>	-----	<i>Zamites confusus</i> , mid Jura of Europe.
<i>Zamites Rolkeri</i>	<i>Zamites Rolkeri</i> , Trias of Honduras	<i>Otozamites Hislopi</i> , Jabalpur group Upper Gondwanas.
<i>Araucarioxylon mexicanum</i>	-----	<i>Araucarioxylon Lindleyi</i> , Lias of England.
<i>Phœnicopsis</i> sp.	-----	<i>Phœnicopsis</i> of European Lias.
<i>Næggerathiopsis Hislopi</i>	{ <i>Næggerathiopsis Hislopi</i> , Rhætic of Tonkin, and Trias of India, South America and Honduras.	-----
<i>Yuccites Schimperianus</i>		<i>Yuccites Schimperianus</i> , Oölite of Europe [Italy].
<i>Trigonocarpus oaxacense</i>	-----	<i>Trigonocarpus</i> [Paleozoic].
<i>Rhabdocarpus grandis</i>	-----	<i>Rhabdocarpus</i> [Permian].
<i>Alethopteris mexicana</i>	-----	<i>Alethopteris</i> forms of European Rhætic.
<i>Cladophlebis Albertsii</i>	<i>Cladophlebis Albertsii</i> , European Wealden.	-----
<i>Coniopteris</i> cf. <i>hymenophylloides</i>	-----	<i>Coniopteris hymenophylloides</i> .
<i>Dicksonia</i> (<i>Sphenopteris</i>) cf. <i>bindrabunensis</i>	-----	<i>Dicksonia bindrabunensis</i> , Liassic of Rajmahal Hills.
<i>Glossopteris linearis</i> ...	? <i>Glossopteris linearis</i> , Upper Paleozoic of Australia	<i>Glossopteris angustifolia</i> , Rhætic of Tonkin.

TABLE I—(Continued).

MIXTECA ALTA SPECIES.	RECURRENT SPECIES.	AFFILIATED FORMS.
<i>Glossopteris mexicana</i> .....	.....	<i>Glossopteris indica</i> , Rhätic of Tonkin.
<i>Laccopteris</i> (?)	<i>Laccopteris</i> near <i>L. Münsteri</i> in Trias of Sonora	<i>Laccopteris Münsteri</i> , Rhätic, Europe.
<i>Sphenopteris</i> cf. <i>Williamsoni</i> .....	.....	<i>Sphenopteris Williamsoni</i> , Inferior Oölite of Yorkshire.
<i>Sagenopteris rhoifolia</i> var. <i>Mexicana</i> .....	.....	<i>Sagenopteris rhoifolia</i> , Rhätic, Europe.
<i>Teniopteris</i> cf. <i>Danæoides</i> .....	.....	<i>Teniopteris Danæoides</i> , Damuda Division, India.
<i>Teniopteris Zeilleri</i> ..	<i>Teniopteris Zeilleri</i> , Rhätic of Tonkin.	.....
<i>Teniopteris</i> cf. <i>vittata</i> ..	.....	<i>Teniopteris vittata</i> , Yorkshire Lias, Great Oölite.
<i>Equisetites</i> (Calamites) <i>Gümbeli</i>	<i>Equisetites</i> (Calamites) <i>Gümbeli</i> , Upper Trias of Franconia.	.....

(a) *Composition of the Mixteca Alta Flora.*

In interpreting Table I it is primarily necessary to recall that in the plant beds outcropping on the Barranca Consuelo the most of the coal occurs near the middle of the lower half of the whole thickness of 550 or more meters; while the coal is followed in the upper portions of the lower half of the beds by a well-marked series of alternating ferruginous sands, shales and grits, during the deposition of which changes in the flora seem to have mainly occurred. And it is here that the older types of ferns and the Cordaiteans appear to drop out. At any rate it becomes worth while to further range the plants of the lower half of the beds side by side with those of the upper half, recalling that the greatest comparatively barren stretches in the great section of the Barranca Consuelo plant beds occur in the initial and final hundred meters. See the appended Table II.

On scanning Table II several most interesting facts appear. In the first place it is most surprising that so few of the species of the lower half of the Consuelo section continue with certainty into the upper half. And this fact, surely not entirely due to the fortunes of collecting, appears the more unexpected since any division of the beds of the section into a lower and upper series would be quite arbitrary. However there are observable some changes in dip and deposition, and that continuation of study afield which is always urgent may yet reveal more than a single unconformity.

TABLE II.—Occurrence of Plants in the Rio Consuelo Section.*

LOWER 250 METERS.	UPPER 300 METERS.
<p><i>Anomozamites</i> cf. <i>Lindleyanus</i> (T.) <i>Otozamites hespera</i>. <i>Otozamites hespera</i> var. <i>intermedius</i>. <i>Otozamites Mandelslohi</i>. <i>Otozamites Molinianus</i>. <i>Otozamites paratypus</i> (T.) <i>Otozamites obtusus</i> var. <i>Liassicus</i> (T.) <i>Otozamites obtusus</i> var. <i>oaxacense</i>. <i>Otozamites (Otopteris)</i> sp. <i>Otozamites Reglei</i> (variety). <i>Otozamites (Williamsonia) tribulosus</i>. <i>Pterophyllum</i> cf. <i>contiguum</i>. <i>Pterozamites (Pterophyllum) angustifolia</i>. <i>Stangerites oaxacense</i>. Williamsonia fructifications : <i>W. Huitzilopochtli</i> (M). <i>W. Mexicana</i>. <i>W. Tlazolteotl</i>. <i>W. Xipe</i> (M). <i>W. (species)</i>. <i>Zamites confusus</i> [var.]. <i>Zamites Rolkeri</i> (Puebla). <i>Araucarioxylon mexicanum</i>. <i>Neggerathiopsis Hislopi</i>. <i>Trigonocarpus oaxacense</i>. <i>Rhabdocarpus grandis</i>. <i>Alethopteris mexicana</i>. <i>Laccopteris</i> (?). <i>Sagenopteris rhoifolia</i> var. <i>mexicana</i>. <i>Equisetites (Calamites) Gumbeli</i>.</p>	<p><i>Cycadeospermum oaxacense</i>. <i>Cycadolepis mexicana</i>. <i>Otozamites cardiopteriodes</i>. <i>Otozamites hespera</i> var. <i>latifolius</i>. <i>Otozamites Reglei</i> var. <i>lucerenis</i>. <i>Otozamites (Williamsonia) Aguilariana</i>. <i>Otozamites (Williamsonia) Diazii</i>. <i>Otozamites (Williamsonia) Juarezii</i>. <i>Otozamites (Williamsonia) oaxacensis</i>. <i>Ptilophyllum acutifolium</i> var. <i>maximum</i>. <i>Ptilophyllum acutifolium</i> var. <i>minor</i>. <i>Ptilophyllum pulcherrima</i>. <i>Pterophyllum Münsteri</i>. Williamsonia fructifications : <i>W. Centeotl</i>. <i>W. Cuauhtemoc</i>. <i>W. Ipalmemoani</i>. <i>W. Nathorstii</i>. <i>W. Nezahualcoyotl</i>. <i>W. Quetzalcoatl</i>. <i>W. Texcatzoncatzl</i>. <i>W. Tlazolteotl</i>. <i>W. Xicotencatl</i>. (Williamsonian stems). <i>Phœnicopsis</i> sp. <i>Yuccites schimperianus</i>. <i>Yuccites schimperianus</i> var. <i>oaxacense</i>. <i>Cladophlebis Albertsii</i>. <i>Coniopteris</i> cf. <i>hymenophyllioides</i>. <i>Dicksonia (Sphenopteris)</i> cf. <i>bindra-bunensis</i>. <i>Glossopteris linearis</i>. <i>Glossopteris mexicana</i>. <i>Sphenopteris</i> cf. <i>williamsoni</i>. <i>Tæniopterois</i> cf. <i>daneoides</i>. <i>Tæniopteris Zeilleri</i>. <i>Equisetites (Calamites) Gumbeli</i>.</p>

Secondly, the distinctly greater proportion of cycads in the initial two-fifths of the section was scarcely to have been expected. But notwithstanding the differences noted, there is a general unity and resemblance in the two series of plants.

The most important fact brought out by grouping the plants as in Table II is, of course, this greater proportion of cycads in the lower half. Taking the beds as a whole, they contain the largest cycadophytan element yet reported, and the fact

* The only species arbitrarily included in this section are several frond types from the Tlaxiaco River, marked T., fruits from Rio Mixtepec (M.) and one Puebla species.

that these plants culminate in numbers low down in the Seccion Consuelo, which is below shown to be typical Liassic, proves that,—*wherever we find beds yielding 60 per cent or more of cycadophytans in fairly representative collections, we may confidently assign them to the very earliest Lias.*

I have already pointed out in my recent paper on the Williamsonian Tribe that the Cycadophytan genera culminated in the Lias, and it may now be regarded as clearly established that the beginning of that period witnessed the maximum development of cycadeous plants in both variety and actual numbers.

A further thought also comes to mind. While it is fortunate that we can here deal with an actual plant succession on a large scale, and while it is true that the species of the upper half of the beds do not vary greatly in general type from those of the lower, it is none the less reassuring to find that were the two series found far separated, most paleophytologists would, with little doubt, reach a fairly correct deduction as to the true relative age. The presence of *Næggerathiopsis* in at least two distinct leaf species would in itself have some weight in favor of the greater age of the plants of the lower beds, while the rather older appearance of the accompanying ferns would scarcely be overlooked. And that such observations should have some value in aiding us to adjudge remotely separated geologic sections is fair to emphasize.

Accordingly, the more general group proportions of the plants of the lower and upper half of the section are further compared by percentages in Table III. And following this suggestive table a similar comparison with more widely separated floræ, interesting because of similar age or because of geographic position, becomes instructive.

TABLE III.—Plant Grouping in the Rio Consuelo Section.

%s	Species in the lower 250 meters	Species in the upper 300 meters	Entire section by direct count
Cycads	(18) + = 72	(20) = 66	70
Ferns	(3) + = 12	(7) = 23	18
Cordaites	3 + = 12 +	(?)	[8]
Conifers	1 = 4		2
Equisetums	(1)	(1) = 3	2
Total species ..	25 +	30 +	

In Table III several lesser rectifications are made, the principal one being the cutting out of the most of the cycad fruits of the upper beds. Since but three to four characteristic Williamsonian fruit species were found in the lower beds, it is better to take arbitrarily a similar number from the upper beds instead of the eight or ten species there found. By so doing, the comparison is made to rest on foliage forms as it mainly should, recovery of fruits being as yet more a matter of chance; while the number of species compared remains about the same because of the passage of *Pterophyllum* and *Otozamites Reglei* forms from the lower into the upper beds. The great preponderance of Cycadophytan frond species in the lower beds is thus brought out. And in fact it seems certain that this excess is more likely to be increased than diminished by future collecting. Most of the non-determinable material occurs in the lower beds, and it seems probable that they will always be found to contain from 6 to 10 per cent more cycad species than the upper beds.

The apparent suppression of the ferns in the collections from the lower strata of the plant beds of the Seccion Consuelo is, however, believed to be due solely to the fact that collecting has not progressed far enough to bring to light as representative a list as in the case of the cycads. That a list of ferns comparable in variety of species to that of the Yorkshire Coast oölites or the Bornholm Lias will yet be obtained, is deemed most likely; but that the cycads will continue to form over half the recovered flora seems still more probable. They seem even to so sharply thrust the ferns aside as to suggest that between the wane of the older seed ferns and the appearance of the modern fern genera there was an interim distinctly poor in ferns.

(b) *Relative Abundance of Cycadophytans in the Mixtecan Flora.*

As just pointed out, the great and dominant feature of the Mixteca Alta flora is its 70 per cent of Cycadophytans. In fact these forms are so strikingly abundant that comparisons with other floræ, made with direct reference to the cycads, are most desirable. These we shall proceed to give, after remarking that it seems improbable that future collection will markedly change the proportions observed. Indeed, evidence for the presence of various well-marked cycad species additional to those described [in my memoir] was at various times noted in the field. And, moreover, in my judgment, a distinctly if not over-conservative method has been followed in referring to a large proportion of the cycads collected as varieties, in order to avoid duplications of species which might later embarrass workers with more extensive material in their hands. Hence

I am disposed to give to every single species and variety of cycad foliage, and to every fruit illustrated, a full unit value.

That we shall not be seriously misled in so doing is my confident belief; for despite all possible duplication of species due to dissociation of fruits from leaves to which they pertained, the abundance of cycadophytans is clearly extraordinary throughout the Mixtecan strata. In fact, without actual count of forms directly from the specimens, a matter of considerable difficulty, the general impression remains that probably 90 per cent of all the forms collected are leaves or fruits of cycadophytans. Whence there can be little doubt that whatever the increase in other types as collection goes on, fully fifty valid species of cycads will be found in the Mixtecan horizons, and probably many more. On listing the various forms so far definitely determined, the following percentages appear:

TABLE IV.—*Rhät-Liassic Flora of Mixteca Alta.*

Cycadophytans (10% Pterophyllums).....	42 forms	= 70 %
Ferns { Old types.....	6 "	= 10
{ Modern types.....	5 "	= 8
Cordaïtes	5 ± "	= 8
Conifers (Araucarioxylon)	1 "	= 2
Equisetum	1 "	= 2
	60 forms	100

In considering Table IV it is to be noted that because of the large proportion of cycad fruits and a relatively poor conservation of ferns in most strata of the Consuelo section, already commented on, the fern element appears unduly small. There is probably, therefore, no very strongly marked departure from the usual Liassic fern proportion of about one-third of all the plants recovered. But the drop from fully, or over, one-half of all plants in the Rhätic is none the less striking; and although the ferns again seem to reach large relative numbers with the accession of numerous recent types in the late Jurassic and Wealden, the Liassic displacement of ferns and dominance of cycadophytans is inescapably clear. These relations at once appear from the summary (Table IVa) of the Rhätic flora of Tonkin, as so fully and thoroughly elaborated by Zeiller.

TABLE IVa.—*Rhætic Flora of Tonkin.*

Ferns (mainly older types)	26 species	= 48 %
Cycads (largely Pterophyllums)	18 "	= 33.5
Conifers (Ex. <i>Nœggerathiopsis</i> = <i>Cordaïtes</i>)	5 "	= 9
Equisetums	3 "	= 5.5
<i>Ginkgo</i>	1 "	= 2
	54 species	

Summarily put: In the Rhätic flora half of the plants are ferns or "Pteridosperms," one-third are cycads, one-tenth are modern gymnospermous types; while the dwindling but still distinct *Equisetum* element forms a twentieth part, and *Cordaites* still persists.* In the Liassic only a strong third of the plants are ferns mostly of markedly modern type, while the cycads increase from 40 to 50 per cent of all plants and *Equisetums* and *Cordaites* tend to disappear with the advent of modern coniferous types. Obviously, as already inferred, the later Rhätic and early Lias witnessed some of the most profound changes known in the history of plants. In the Rhätic, then, diversity of *Pterophyllums* with the complete recession of the *Equisetums* and *Cordaitaleans* are the dominant features. But the old types of ferns, presumably still including many seed-bearing kinds, still continue to outnumber all other groups, and the displacement of the *Cordaitaleans* only seems to foreshadow the advent of the conifers, as yet far from abundant or well marked.

The course of change as the Liassic advances is well indicated by the Bornholm and Yorkshire Coast floræ, which are here appended in their proper order, and followed by a resumé in Table V, in which are also included the more recent floræ of Graham Land and Oroville, along with the Rajmahal Hills proportions.

TABLE IVb.—Liassic Flora of Bornholm.

Ferns (of old and modern type)	27	species	=	35.5 %
Cycadophytans (one-fifth <i>Pterophyllums</i>) ..	25	"	=	33
Conifers	13	"	=	17
Ginkgos	7	"	=	9
<i>Equisetums</i>	4	"	=	5
<hr/>				
76 species				

*It is instructive to go back a step further and note general proportions in the Lunz of Austria. This highly interesting flora has recently received the attention of Krasser, although yet lacking a final description. The Lunz flora of some 41 determined species consists of 44 per cent ferns, 39 per cent cycadophytans, 2 per cent conifers, 5 per cent *Cordaitaleans*, and 10 per cent *Equisetums* and *Calamariales*. The pre-Jurassic type of this flora is quite apparent when the large *Equisetum* element is noted, and it is sufficiently emphasized that the rather high percentage of cycadophytans is due to the fact that the *Pterophyllums* culminate in the Lunz and thus form in that period the crest of the first wave of the Cycadophytan advance in the Mesozoic, which reaches its climax in the Lias. Similarly the litigious genera *Ctenis* and *Pseudoctenis* provisionally included in Cycadophytans go to swell the cycad percentages of the Oölite. To fully understand the percentages one must hold such facts in mind.

TABLE IVc.—*Inferior Oölite of Yorkshire Coast.*

Ferns	20 species	=	37%
Cycadophytans	23 "	=	42
Conifers and Ginkgos	9 "	=	17
Equisetums	2 "	=	4

54 species

TABLE V.—*Elements of Typical Rhätic—Oölitic Floræ.*

%s	Graham Land Mid-Jura	Oroville Oölite	Yorkshire Inferior Oölite	Bornholm Lias	Rajmahal Hills Lias	Oaxaca Lias to Rhätic	Tonkin Rhätic	Averages
Ferns	42	46	37	35	32	18	48	37
Cycadeans	28	38	43	33 +	34 +	70	33	40
Conifers ..	27	12	16	17	8	(2)	9	13
Ginkgos ..	--	4		9	?	--	2	2 ±
Cordaites ..	--	--	?	?	?	8	2	2 +
Equisetums	2	?	4	5	2	2	5.5	3

Before passing the comparisons afforded by the preceding tables, it may be mentioned that they show still more clearly the general course of change from Rhätic to mid-Jurassic times when necessary modifications are borne in mind. Thus the percentage of cycads in the Bornholm flora is relatively lower, because not augmented by fruits; while the Yorkshire Coast cycad percentage would also be higher were the fruits more recently discovered by Nathorst included. In general there is, indeed, much of consonance in these figures, and it will certainly be of interest, as the species are from year to year augmented and revised, to make the necessary corrections as well as to add the statistics of other regions. Having brought to view the general composition of the Mixteca Alta flora and made clear the fact that it contains a relatively more numerous cycad element than any other, we pass on to a further consideration of the indicated age.

(c) *Age of the Plant Beds of the Seccion Consuelo.*

In order to throw into strong contrast the course of change in early to mid-Mesozoic forest components and further illus-

trate both the advantages and the limits of the method pursued in determining the age of the Oaxacan plants, it will not be found amiss to take a hasty glance at plant proportions in the Lower Cretaceous—a rapid survey which has been rendered easy by Berry's recent résumé of the Lower Cretaceous floras of the world.

This more distant comparison with the Lower Cretaceous is not without tangible interest and may be given a concise enough form for interpolation. For this purpose Table Va has been prepared to show the main elements of twelve of the more striking Lower Cretaceous floras.

TABLE Va.—*Twelve Lower Cretaceous Floras.*

%s	Neocomian, Japan.	Upper Knoxville.	Wealden, England.	Wealden, Uitenhage.	Kootanie.	Wealden, Germany.	L. Cretaceous, Portugal.	Potomac.	Urgonian, Austria-Hungary.	Komé.	Aptian, Portugal.	Albian, Portugal.	Averages %.
Ferns	43	38	37	38	40	54	47	32	17	45	28	30	40·
Cycadeans	47	38	35	33	21	18	10	25	38	12	8	9	23·
Conifers	7	11	11	28	28	21	21	22	17	20	44	18	22·
Angiosperms	—	(?)	—	—	—	—	—	17	0	10+	12(?)	32	14·+
No. of species	28	36	70	21	88	33	95	134	29	75	23	66	

Naturally there are sharp limits to accuracy in so compacted a form of presentation. And, of course, the defectiveness of the plant record is much accentuated by the small size and obvious aberrancy of several of the floras more or less arbitrarily included. Indeed, at first sight such a table appears to have a rather minor value, and one is mainly aware that no one has ventured to present it hitherto; while every paleontologist knows well that these general percentages may even be as little accurate for the floras actually recoverable in a given region, as representative of the ancient plant proportions.

Nevertheless, there is more than a mere assumption that the inaccuracies so obviously and inherently involved in no considerable degree balance each other. For neither the exigencies of fossilization, nor climatic variation, nor yet the varying personal equation involved in the determination of these fragmentary records from many lands, can wholly obscure the larger outlines of Cretaceous vegetation. Generally consistent and inescapably salient are the following features:

Firstly, Cordaites which still held a fast lessening place in the early Jura leaves behind only a few lingering hypothetical forms like *Eolirion*.

Secondly, the Equisetums left over in the Jura-Rhætic groups are now positively reduced to present day scant numbers.

Thirdly, the high frequency of ferns represents the culmination of the mid-Mesozoic fern recrudescence due to the spread of the more strictly modern types, as mentioned further on.

Fourthly, the persistent presence of conifers in numbers at first sharply increasing and then followed by decline in both the percentage and actual number of species recovered, is in striking contrast to the moderate numbers of the lower Jura. It may, in fact, be definitely accepted that, taking the world over, a strong fifth of lower Cretaceous vegetation was coniferous. This is the proportion in the English Wealden, in the Potomac, and apparently in all the horizons where collecting has been most thorough. The 44 per cent of the Portuguese Aptian and 7 per cent of the Japanese Neocomian balance each other as abnormal proportions unquestionably due to lack of fortune afield. In a word, just as the early Jura was a period of vast reaches of Williamsonians, so quite all the Lower Cretaceous was the time of dominant coniferous forests which receded with the advance of the angiosperms.

Fifthly, the cycadophytan and coniferous elements quite exactly balance each other, the time when these gymnospermous types are to reverse their Jurassic proportions being near at hand.*

The preparation of Table II at once showed that the lower half of the Consuelo plant beds contains elements which any paleobotanist would, as already insisted upon, recognize as belonging to a slightly older facies than the plants of the upper half. That is to say, even were these two series of plants obtained in widely separated regions, the fact that they bear a successional rather than an equivalent relation would be evident. Nevertheless, the difference is, in the present state of our knowledge of Lower Jurassic floræ, not strongly enough pronounced to permit more than fairly taken surmises. Especi-

* Where these floræ do vary markedly from the expected or average type, restudy in both laboratory and field is urgent. Take for instance the Urgonian of Austria-Hungary. If the commonly found ferns and conifers of Urgonian time were arbitrarily added to that list, the normal proportion of about 45 per cent ferns, 20 per cent cycads and 25 per cent conifers would at once be had, and the presumption is strong that either additional ferns can be found in the formations in question, or else we must take the only remaining alternative view that the series is of somewhat aberrant early Wealden type.

Similarly in the Wealden of Germany we may arbitrarily declare that the reverse holds, cycad and conifer collection and determination having failed to keep pace with fern recovery. At least the cases cited offset each other and the burden of proof must primarily rest on any explanation invoking changed local conditions, sufficient to account for such deep-seated variations as would be indicated were some of the German Wealden proportions found approximately true ones.

ally is this so because of the lack of other sections yielding as abundant and exactly located forms throughout such great thicknesses of strata. In this respect the Rio Consuelo section is so nearly unique that it has been found necessary to regard the plant beds as a unit when attempting comparison with other sections.

Consequently in any first effort to determine the relative age of these beds it is safest to fix the attention on a thoroughly simplified list of the plants of the entire section. And such a list of positive value is best obtained by excluding from Table I the varieties, the sole Equisetum, the Tæniopterids, the doubtful Glossopterids, and most of the cycad fruits which so far have been of much too seldom occurrence for grouping according to age. By thus dealing with the larger features—the irreducible minimum of genera and species to which no one can take exception, rather than resting the case on more or less moot species, the chances for error must be very markedly lessened. The list when condensed is as follows:

TABLE VI.—Condensed list of Mixteca Alta Plants.

Cycads = 60% +	Gymnosperms of non-cycadaceous ancient type = 15% ±	Ferns of old and new types equally divided = 20% +
<i>Anomozamites Lindleyanus</i>	<i>Araucarioxylon</i>	<i>Alethopteris</i>
<i>Cycadolepis</i>	<i>Neggerathiposis</i>	<i>Cladophlebis</i>
<i>Cycas</i> (?)	<i>Rhabdocarpus</i>	<i>Coniopteris</i>
<i>Podozamites</i> sp.	<i>Trigonocarpus</i>	<i>Sagenopteris rhoifolia</i>
<i>Ptilophyllum</i>		<i>Sphenopteris</i>
<i>Otozamites obtusus</i>		<i>Tæniopteris Zeilleri</i>
“ <i>Reglei</i>		
“ <i>Molinianus</i>		
“ <i>Mandelsohi</i>		
“ <i>hespera</i>		
“ <i>paratypus</i>		
“ <i>Diazii</i>		
“ <i>Juarezii</i>		
<i>Pterophyllum</i> cf. <i>contiguum</i>		
“ <i>münsteri</i>		
<i>Pterozamites angustifolium</i>		
<i>Williamsonia</i> (stems and fruits in profusion)		
<i>Williamsonia mexicana</i>		
<i>Zamites Rolkeri</i>		

Bearing in mind, now, that it is not the new species of a more or less cosmopolitan early to mid-Mesozoic flora, however broadly identified, but the old and better known elements that must in the primary instance afford a basis of comparison, it is well to take both the trouble and the space to give the age usually assigned to the better known elements recurring in the Mixteca Alta flora in a further subjoined table, VIa.

TABLE VIa.—Assigned Age of Oaxacan Plants.

Rhätic (or Triassic)	Liassic	Oölitic
<i>Zamites Rolkerei</i>	<i>Ptilophyllums</i>	<i>Ptilophyllums</i>
" <i>confusus</i>	<i>Otozamites obtusus</i>	<i>Otozamites</i> (<i>Williamsonia</i>)
<i>Pterophyllum</i> cf.	" <i>Molinianus</i>	<i>Williamsonia</i> (fruit species)
" <i>contiguum</i>	" <i>Mandelslohi</i>	<i>Yuccites</i>
<i>Laccopteris</i> (?)	" <i>Reglei</i>	
<i>Næggerathiopsis</i>	" <i>Juarezii</i>	
<i>Alethopteris</i>	<i>Pterozamites</i> (<i>Ptero-</i>	
<i>Glossopteris</i>	phyllum)	
	<i>Pterophyllum</i> (<i>mün-</i>	
	steri)	
	<i>Anomozamites Lind-</i>	
	leyanus	
	<i>Cycadolepis</i>	
	<i>Phœnicopsis</i>	
	<i>Stangerites</i>	
	<i>Sagenopteris</i>	
	(Rhät to Lias)	

It is here seen that when keeping in mind the specimens themselves, as well as lists, about eight of the old elements are upper Triassic or Rhätic, and only four are of somewhat Inferior Oölitic stamp, while the great bulk of the forms are "Liassic." *It is, therefore, found that the plant beds of the El Consuelo section begin at the upper borders of the Rhätic and probably extend through the Liassic near to the lowermost Inferior Oölitic.*

And in so far as the position of the plant beds is open to dispute and adjudication following the critical study of the invertebrates of the great series of superposed marine deposits in the El Consuelo Section, I would first yield by classing the plant beds still more simply as youngest Jurassic. The flora, as already explained, appears to have been but briefly established rather than old, a fact quite in accordance with the sequence of geologic events leading up to the deposition of the plant beds.

Such is the academical result; for we hold that no part of the plant beds can be Rhätic. As already quoted, Zeiller has shown that a typical Rhätic flora (that of Tonkin) which actually contains some elements found to persist in Oaxaca, is half made up of ferns of the older type, one tenth of the plants being conifers and only one-third cycads. While on the other hand, there is much more of agreement in the Liassic proportions for these forms as already displayed in Tables IV-V.

Moreover, we encounter difficulties as soon as an attempt is made to draw close parallels with presumably post-Liassic floræ. That from Oroville, California, appears much more recent in type. So does that of Graham Land.

(d) *Source of the Mixteca Alta Flora.*

Are these Oaxacan plants northern or southern in origin? Or, are they essentially equatorial, and such a distinctive part of the more strictly cosmopolitan vegetation of the Jura that no source or original home of the major elements can be discerned?

It is unfortunate that sections through the plant beds of the Argentine or other South American mainland localities yielding Jurassic plants have not been made by qualified plant collectors; whilst all we so far have from Antarctica is the recently published work of Halle on the Mesozoic flora of Graham Land. A brief note of Nathorst in the *Compte Rendu* (p. 1449, June 6th, 1904) first made it known that a varied vegetation resembling that of the Jabalpur-Kach beds of India, and, therefore, affiliated with the Northern floræ of early to decidedly mid-Jurassic facies, once flourished in Antarctica. And a little later the study of this notable material was taken up by Halle.

Typical Graham Land plants are *Cladophlebis*, *Todites*, *Coniopteris*, Sphenopterids, *Otozamites Hislopi*, *Pseudecten*, a *Pterophyllum Morrissianum* equivalent, and a notable group of conifers including *Araucarites cutchensis*, *Pagiophyllum*, *Brachyphyllum*, and *Elatocladus Jabalpurensis* (= *Palissy*), with various other less important species.

Evidently many of the most conspicuous plants of early Jurassic and later time were nearly as distinctly cosmopolitan as the Paleozoic types, a fact which must make the unravelling of the course of plant origin and migration in the mid-Mesozoic or "proangiosperm" age an exceedingly complicated if not virtually impossible task. But, needless to say, the difficulty here confronted must incite paleobotanists to put forth every effort before finally accepting negative results.

Meanwhile, such evidence as we do possess at least makes possible various interesting inferences. As already noted,

Næggerathiopsis appears to have come from the South; so also any Glossopterids. And while it is difficult to detect other southern elements, there is in Oaxaca the curious absence of conifers of northern type and especially of *Ginkgo*, so far a very distinctly northern form. The more typically Indian net-veined cycad *Dictyozamites* is also lacking, though sparingly found on both the Yorkshire Coast and at Bornholm, and now known to have occurred in the Antarctic realm, as very recently reported by Halle.

TABLE VII.—Notable Old World Types not yet Found Recurrent in Oaxaca.

India.	Yorkshire.
<p>(1) Liassic : Rajmahal Hills flora :</p> <p><i>Tæniopteris lata</i> <i>Macroteniopteris lata</i> <i>Cycadites rajmahalensis</i> <i>Pterophyllum Morrissianum</i> <i>Pterophyllum princeps</i> <i>Pterophyllum rajmahalense</i> <i>Pterophyllum crassum</i> <i>Pterophyllum distans</i> <i>Paleozamia bengalensis</i> <i>Dictyozamites falcatus</i> <i>Dictyozamites indicus</i> <i>Sphenopteris Hislopi</i> <i>Taxodites (?) indicus</i> <i>Palissya conferta</i> <i>Ginkgo crassipes</i> <i>Thinnfeldia indica</i></p> <p>(2) Oölite : Kach-Jabalpur :</p> <p><i>Ginkgo lobata</i> <i>Palissya indica</i> <i>Palissya jabalpurensis</i> <i>Echinostrobus expansa</i> <i>Ctenis Nathorstii</i></p>	<p>(1) Lias :</p> <p><i>Cycadites rectangularis</i>.</p> <p>[On Bornholm occurs <i>Dictyozamites Johnstrupi</i>.]</p> <p>(2) Inferior Oölite.</p> <p><i>Ginkgo digitata</i>. <i>Baiera gracilis</i>. <i>Taxites zamioides</i>. <i>Dictyozamites Hawelli</i>. <i>Nilssonson mediana</i>. <i>Ctenis falcata</i>. <i>Ctenis Nathorstii</i> (Bornholm). <i>Matonidium Gæppertii</i>. <i>Dictyophyllum rugosum</i>.</p>

But we should not make too much of these facts. Far more noticeable is the absence of the large forms of *Pterophyllum* and especially of *Ctenis*; for the recurrence of these major elements of the Indian Lias in the supposedly younger Oroville flora of course suggests a long persistent great northern route or rather center of origin.

Taking the facts at hand, it appears that the Oaxacan plant beds were not notably indebted to Indian or southern regions. At least this is a fair conclusion from the suprajoined Table VII giving important old world types not yet known to recur

in Oaxaca.* The Indian Liassic and Californian plant equivalence is as follows:

TABLE VIII.—Recurrence of Indian Types in California.

Indian Liassic.	California [Oölite.]
<i>Pterophyllum rajmahalense</i> ,-----	<i>Pterophyllum rajmahalense</i> .
<i>Pterophyllum Morrissianum</i> ,----- [near]	<i>Ctenophyllum densifolium</i> .
<i>Pterophyllum princeps</i> , {	[near] <i>Ctenis grandifolia</i> .
<i>Pterophyllum crassum</i> , {	
<i>Pterophyllum distans</i> , {	
<i>Cycadites rajmahalensis</i> ,-----	[Recurs in North Carolina Trias.]
<i>Tæniopteris lata</i> , {	[near] <i>Macrotaeniopteris californica</i> .
<i>Macrotaeniopteris lata</i> , {	

To the lists of Table VII could, of course, be added the plants which are new at Bornholm. But it is a trifle more convenient to give these separately as follows:

- (1) *Dicksonia Pingelii*
- (2) " *pauciloba*
- (3) *Asplenites Cladophleboides*
- (4) *Hausmannia acutidens*
- (5) *Ctenis Nathorstii*
- (6) *Otozamites bornholmiensis*
- (7) " *Bartholini*
- (8) *Otozamites pusillus*
- (9) " *tenuissimus*
- (10) *Dictyozamites Johnstrupi*
- (11) *Pagiophyllum falcatum*
- (12) " *triangulare*
- (13) *Taxites subzamioides*
- (14) *Carpolithes nummularius*

Bornholm is only separated from the Yorkshire Coast by 15° of longitude on the approximate 55th parallel of north latitude; and its Lower Jurassic plant beds must be a near

* A most interesting habitus feature of the Mexican *Ptilophyllums* is the number of fronds characterized by a pinnule insertion intermediate between the linear or *Pterophyllum* and the stemmed or *Podozamites* type. And this gradual transition through the *uni-* or *anterolobate*, faintly *posterolobate* and finally distinctly *bilobate* insertion, is in distinct agreement with the great variety of stem and floral structure. As these pages go to press, a study of the porcellaneous specimens from the Rajmahal Lias by Miss Bancroft comes to hand, and the details brought to view further emphasize how completely the work of the past few years has broken down the barriers between the *Cycadeoideæ*, *Williamsonians*, and the existing cycads, bringing to view a varied and vast but homogeneous group. In particular the nodal type of stem brought to definite notice in my paper on the *Williamsonian Tribe* proves of intermediate type. Growth rings are not found strong, perhaps because the preservation in light color makes their observation difficult; but even this difference from *Dion* is now broken down, as I find that some of my sections of *Cycadeoideæ* show the growth rings distinctly.

succession of the Rhätic of Skone. With the latter the Bornholm flora has nineteen species in common, with the Rhätic of Franconia the same number, with the Rhätic of Poland fifteen, and with the Inferior Oölite of Scarborough about an even dozen. These species common to Bornholm and Scarborough it is of convenience to recapitulate here as follows :

- (1) *Equisetites columnaris*
- (2) *Sagenopteris Phillipsii*
- (3) *Cladophlebis denticulata*
- (4) *Coniopteris* cf. *hymenophylloides*
- (5) *Dictyophyllum* cf. *rugosum*
- (6) *Laccopteris polypodioides*
- (7) *Podozamites* cf. *lanceolatus*
- (8) *Ginkgo* cf. *digitata*
- (9) *Baiera* cf. *gracilis*
- (10) *Czekanowskia* cf. *Murrayana*
- (11) *Otozamites obtusus*
- (12) *Dictyozamites* cf. *D. Hawelli*
- (13) *Nilssonina* cf. *Compta*

As the Bornholm plants include *Dictyozamites*, conifers, and *Ginkgo*, so far an exclusively northern type, a strong parallel with the Yorkshire Coast is presented despite a difference in age. But the cycad element of the Bornholm flora also includes the two important species *Otozamites Molinianus* and *O. Mandelslohi* characteristic of the Lias of continental Europe and recurrent in Oaxaca. When therefore, the resemblances to the Oaxacan flora to be found at Bornholm and the Yorkshire Coast, and in continental Europe, are all brought together (cf. Table I) it is found that they much outweigh the resemblances noted in the Indian series. Moreover, there is a certain unity in the flora of the northern latitudes, which suggests that north and south routes were the ones most travelled by plants in the early Jura, and throws into much doubt the existence of an equatorial Gondwanaland center of origin or route at the time the Oaxacan plants flourished. *Such a direct connection with the old world should have resulted in far sharper resemblances to some one of the European or Indian floras than any so far detected.* In the equable uniform tropic conditions of a hypothetic Gondwanaland, plant migration would apparently have been so easy and rapid as to readily reproduce in the early Jura striking conformities such as still characterized vegetation at the beginning of the Mesozoic. But with no approach to any such uniformity in evidence, it is far safer to hypothesize northern and southern centers of origin.

To rush to the opposed view that, since in all probability the Oaxacan series belongs to the very early Jura, it is the pre-

cursor of either northern or southern floras, appears entirely gratuitous. The lack of the cosmopolitan *Dictyozamites*, together with the apparent absence of conifers and Ginkgos, points the other way. The general movement of plants in more recent time is also against such a view; and it is pertinent to iterate here that it has too long been the custom of paleontologists when comparing the fossils of remote horizons to imagine that the similarities observed are due to some constant interchange of species, originating locally and more or less by chance. Too often this idea of the crossing of species and the recrossing half way round the globe is hypothesized in terms excluding the polar areas; for it is only reasonable to suppose that these have always been relatively more instead of less prolific of new species than equatorial regions.

Unquestionably, when isolated localities are freshly populated, especially islands, considerable specific variation results. But it is a fair inference that species so produced have much less invasive power than those which result from profounder geologic changes affecting the globe as a unit—or better said, perhaps, those species which mark and form the crests of the greater waves of evolutionary development and change. It is, therefore, a strong inference from the general as well as special facts cited that the Oaxacan flora, though no doubt including many forms or varieties of local development, was preponderantly northern rather than southern or mainly equatorial in aspect.

The very few generalizations tentatively outlined here must, of course, await the results of future field work for their proof or disproof. Nevertheless, it does seem that the overlap of new and old forms in the various Jurassic floræ can be satisfactorily dealt with as soon as species are better known. The strong likeness between such widely separated floræ as those just considered betokens regularity in the movement and development of Jurassic plant life. It is, therefore, nearly certain that while it may never be possible to trace the full history of genera or families one after the other, the accumulation of large aggregates of definitely determined species will be equally effective. Aggregates of species should enable us to determine age with accuracy on the basis of the percentage of the major elements, that is the Cordaitaleans, cycads, conifers, ferns and Equisetums, as approximated on Table V. Certainly it seems that eventually it should be possible to establish the curve of frequency for the orders of plants in the several floræ, however erratic may have been the development and spread of some of the genera or families. And so long as such possibility remains open, the incentive to the accurate determination of the Jurassic species is of the strongest.

ART. XXVII.—*The Age of the Eurypterids of Kokomo, Indiana,** by E. M. KINDLE.

THE small but interesting Eurypterid fauna which characterizes the Kokomo limestone of Indiana has recently been admirably described and figured by Doctor J. M. Clarke and Doctor Ruedemann† in connection with the Eurypterid faunas of New York. The opinion concerning the age of this remarkable fauna which these authors express, however, invites discussion since it is at variance with the view of some geologists who have a knowledge of the field relations of the beds holding it and of the formation with which it is correlated. The matter seems to be of sufficient importance to justify a brief review of the evidence bearing on the question of the age of the beds. If, as Clarke and Ruedemann state, the Kokomo Eurypterid fauna is of Lockport age, it may well stand in an ancestral relation to the New York Salina Eurypterid faunas which they describe. This is the conclusion which the reader is apt to draw from an inspection of the tables on pages 91, 93, and 431‡ and the discussion of the new subgenus *Onychopterus* from Kokomo. The other elements of the Kokomo fauna and the stratigraphy of the region do not, in the writer's opinion, bear out this inference.

Clarke and Ruedemann correlate the Kokomo limestone with the Noblesville limestone of Indiana and the Lockport of New York, and use indiscriminately the terms Kokomo limestone, Kokomo waterlime and Noblesville waterlime.§

This correlation is in harmony with a suggestion made by Schuchert, who, in a review of the writer's work on the "Stratigraphy and Palæontology of the Niagara of Northern Indiana," suggested the probable absence "of the water-lime horizon in Northern Indiana."¶ Schuchert was probably in part influenced in expressing this opinion by the still earlier reference of *Conchidium colletti*, the most conspicuous brachiopod of the Kokomo fauna, to the Niagara limestone by Hall and Clarke.¶ The writer had, at the time Schuchert's review appeared, a nearly complete collection of the Kokomo fauna and intended, when opportunity for its illustration offered, to present the strong array of evidence which it furnished against the inferred equivalence of the Kokomo and Lockport faunas. Other duties intervened however, and at a comparatively recent

* Published with the permission of the Director of the Geological Survey of Canada.

† Memoir New York State Museum, No. 14, vols. i and ii, 1912.

‡ Ibid.

§ Ibid, pp. 320, 351, 215.

¶ This Journal, Dec. 1904, p. 467.

¶ Pal. N. Y., vol. viii, pt. II, pl. 66, 1894.

date most of the Kokomo fauna was described by Dr. Aug. Foerste. Now that both the Kokomo and Niagaran faunas of northern Indiana have been described, it is in order to examine the evidence which they afford regarding the question of their equivalence as advocated by Clarke and Ruedemann, or their succession as believed by the writer.

The Kokomo fauna occurs in a limestone which in the earlier references to it was generally called the "water-lime" beds or Water-lime Group.* The name Kokomo limestone was introduced for these beds by Foerste† in 1904. They are exposed in various quarries in the vicinity of Kokomo, where they lie horizontal and are covered by drift except where uncovered by quarry operations. The character of the beds of this limestone and the stratigraphic relations of the eurypterid and non-eurypterid faunas which characterize different parts of them can best be understood by reference to a section of one of the quarries in the Kokomo limestone. The section exposed at the Geo. Defenbaugh quarry on the south side of Kokomo (N. W. $\frac{1}{4}$ sec. 6 T. 23 N. R. 4E.) is as follows:

Section of Kokomo limestone.

1. Drab to grey non-magnesian limestone, with chert bands and containing a brachiopod fauna.....	4'
2. Thin-bedded and finely-laminated dark-grey limestone, with eurypterids, and lying in strata 1"-2" thick which on weathering split still thinner. This bed contains occasional pockets of asphaltum and crude oil.....	6'
3. Grey limestone ("cement rock")	4'
4. Dark-bluish grey argillaceous limestone.....	2'
5. Dark grey limestone in even bedded ledges 6" to 8" thick.....	6'
6. Very hard thin-bedded strata of brownish grey to bluish limestone	6'
7. Blue and light grey banded limestone, the layers very thin, smooth, and even bedded and giving a variegated appearance to the stone	4'
	<hr/> 32'

Eight or ten feet more of beds similar to those of the section given above are penetrated by some of the quarries but these were not seen by the writer. As in the water-limes of New York the eurypterid and non-eurypterid faunas appear to be confined to distinct parts of the section. The writer was able to discover no trace of the brachiopod fauna which characterizes bed number one below it, nor have any eurypterids ever

* E. W. Clappole, Am. Geol. vol. vi, p. 261, 1890. A. J. Phinney, 11th Ann. Rept. U. S. Geol. Surv., pt. I, pp. 632-3, 1891. S. A. Miller, 17th Rept. Ind. Dept. Geol. & Nat. Res., p. 33, 1892.

† 28th Ann. Rept. Ind. Dept. Geol. & Nat. Res. p. 33, 1904.

been found in this bed so far as known. The eurypterids occur in bed number two and probably in various other beds below it. Most of the beds and probably all of them below number one contain a notable amount of magnesia.

The most prominent general characteristic of the lithology of these beds is the very even bedding and generally thin lamination. This strikingly developed feature distinguishes the Kokomo limestone sharply from any of the known types of the Noblesville dolomite. The latter *never* shows thin lamination or marked evenness of bedding. Frequently the bedding planes of the Noblesville are so obscure as to make their recognition difficult. When they are well marked the distinct, clear cut, horizontal, and even lamination of the Kokomo beds is never present. Sometimes, as in the case of outcrops on the Wabash river below Peru, the irregularity of bedding takes the form of cross bedding. The well marked physical peculiarities which distinguish the Kokomo limestone from the Noblesville dolomite are so pronounced that there is no good reason for confusing the two by using such a term as "Noblesville waterlime."*

A geologist familiar with the sharp contrasts shown by the lithology of the Kokomo and the Noblesville formations would indeed be surprised if he found the same fauna in each. But the faunas and the lithology are quite harmonious in indicating that the Kokomo and Noblesville represent entirely distinct formations. The evidence of the fossils can best be shown by presenting a list of the species collected by the writer at the type locality of the Noblesville dolomite for comparison with the fauna of the Kokomo limestone.

Noblesville dolomite fossils from Connors Mill, Hamilton County, Indiana.

- Strophonella* cf. *striata* Hall.
- Strophonella williamsi* Kindle.
- Leptaena rhomboidalis* Wilckens.
- Plectambonites* cf. *sericeus* Sowerby.
- Dalmanella elegantula* Dalman.
- Rhipidomella hybrida* Sowerby.
- Conchidium* cf. *multicostatum* Hall.
- Atrypa calvini* Nettleroth.
- Atrypa reticularis* Linnæus.
- Spirifer nobilis* Barrande.
- Spirifer radiatus* Sowerby.
- Spirifer* (*Reticularia*) *crispa* var. *simplex* Hall.
- Meristina maria* Hall.
- Platyceras* (*Diaphrostoma*) *cornutum* Hisinger.

* Mem. N. Y. State Museum, No. 14, p. 215, 1912.

Iliaenus insignis Hall.
Enerinurus indianensis Kindle.
Calymene vogdesi Foerste.
Ceraurus (*Crotalocephalus*) *niagarensis* Hall.
Phaerexochus romingeri Hall.
Phacops cf. *pulchellus* Foerste.

The list of fossils of the Kokomo limestone which follows is believed to include all of the fossils which have been described from this formation. It is based upon the work of Claypole,* Miller†, White‡, Foerste§, and Clarke and Ruedemann.||

Fossils of the Kokomo limestone, Kokomo, Indiana.

Buthotrephis divaricata David White.
Buthotrephis newlini David White.
Amplexus septatus Foerste.
Favosites pyriform-kokomoensis Foerste.
Chonetes colliculus Foerste.
Leptaena rhomboidalis Wilckens.
Spirifer exiguus Foerste.
Spirifer corallinensis Grabau.
Whitfieldella erecta Foerste.
Anoplothea congregata Kindle.
Dalmanella elegantula Dalman.
Pentamerus divergens Foerste.
Conchidium colletti Miller.
Wilsonia kokomoensis Miller.
Isochilina musculosa Foerste.
Kloedenia kokomoensis Foerste.
Eurypterus ranilarva Clarke & Ruedemann.
Eurypterus (*Onychopterus*) *kokomoensis* Miller & Gurley.
Eusarcus newlini (Claypole).
Stylonurus (*Drepanopterus*) *longicaudatus* Clarke & Ruedemann.

Comparison of the two lists shows that two wholly different faunal types are represented. If we compare the fauna of the Noblesville limestone with that of the whole recorded Niagaran fauna of northern Indiana, that is the combined faunas of the Noblesville and the Huntington, we get a nearly complete discordance. Only a single species, if we except the long ranging *Leptaena rhomboidalis*, is common to

* Am. Geol. vol. vi, pp. 258-260, 1890.

† 17th Rept. State Geol. of Ind. 1891, p. 77, pl. 13, figs. 5-6, 1892. III. State Mus. Bull. 10, 1896, p. 90, pl. 5, fig. 1. 18th Rept. State Geol. of Ind., 1893. p. 312, pl. 9, figs. 22-24, 1894.

‡ Proc. U. S. Nat. Mus., vol. xxiv, pp. 269-270, pl. xvi-xviii, 1901.

§ Jour. Cin. Soc. Nat. Hist., vol. xxi, pp. 1-39, pl. i, 1909.

|| Mem. N. Y. State Mus., No. 14, vol. i-ii, pp. 1-628, pls. 1-88, 1912.

the two. It may be observed that one species which Foerste finds in the Kokomo fauna, *Anoplothea congregata*, was described by the writer in connection with the faunas of the Noblesville and Huntington dolomites, but in connection with the description the statement was made that "the species apparently does not belong to the Niagaran fauna and is probably a representative of the "Waterlime" fauna.* The occurrence in the Kokomo fauna of a *Wilsonia* and of *Dalmanella elegantula* might be cited as suggestive of a Lockport horizon. The *Wilsonia*, however, is a distinct species from that found in the Noblesville and Huntington and the *Dalmanella elegantula* is described as "a small variety" of that species by Foerste. The lack of harmony of the remainder of the fauna with that of the Lockport appears however to indicate that these species represent a heritage from the Lockport. They belong, as Hyatt remarks of certain groups of fossils, to "types which remain comparatively simple, or do not progress to the same degree as others of their own group."† In association with other fossils of distinctly post-Lockport type *Dalmanella elegantula* clearly fills the rôle of a late survivor of an early fauna just as *Phacops rana* does in the Portage or *Rhipidomella vanuxemi* in the Chemung. It is a survivor of a fauna which has been almost completely replaced by later types. The presence in the Kokomo fauna of a *Conchidium* cannot be taken as evidence of its Lockport age. In the Indiana province *Conchidium* persists through the Huntington dolomite, which is the representative of the Guelph in that region. It is true that *C. colletti* is not allied to the Huntington species, but neither is it to any of the Noblesville species of the genus. Its specific characteristics are markedly different from those of any Noblesville *Conchidium*. If comparison of this shell is made with *C. laqueatum*, the form nearest to it in the Noblesville, it will be seen to have about double the number of plications characteristic of that species. The remarkable expansion and flattening of the front of the shell sharply differentiates it not only from this but from all other species of *Conchidium*. It recalls the extravagant expansion in sub-parallel planes of the anterior portion of the shell of *Atrypa reticularis* which is shown by certain varieties in the later stages of its phylogenetic history. A primitive pentameroid feature which some of the Lockport species of *Conchidium* exhibit very distinctly in a non-plicated umbonal area is conspicuously absent in *C. colletti*. The fine plications and their complete extension over the umbones in *C. colletti* suggest that it belongs to the latest surviving type of the genus.

* 28th Ann. Rept. Ind. Dept. Geol. & Nat. Res., p. 445, 1904.

† Phylogeny of an Acquired Characteristic. Proc. Am. Phil. Soc., vol. xxxii, 1895.

Whatever inferences regarding the age of the Kokomo fauna might have been drawn from the two or three species originally ascribed to it in the Indiana Reports, the fauna at present known affords no satisfactory ground for correlating it with the Noblesville dolomite of Indiana or the Lockport of New York. So unlike are the characteristic features of each that no geologist with a knowledge of the Noblesville and Kokomo faunas derived from a field study of the beds holding them would ever be likely to think of the possibility of the identity of the two. Trilobites constitute one of the important and almost invariably present elements of the Noblesville faunules which is entirely absent from the Kokomo fauna. Scarcely a faunule has been collected from the Noblesville by the writer which did not include *Sphaerexochus romingeri* or some other species of *Illænus*. The entire absence from the Kokomo limestone of gasteropods, which are common both in the Noblesville and Huntington formations, serves also to emphasize the difference between the two.

Since a comparison of the faunas does not appear to justify the correlation of the Kokomo with the Noblesville we may next inquire briefly what correlation the fauna does suggest. The only plants which are known from the Kokomo limestone were described by David White from specimens transmitted by the writer. Concerning the relationship of the two new species of *Buthotrephis* which Mr. White recognized in these, he states, "Of all the species as yet ascribed to this genus that which seems to be most closely related to the fossils in hand is *Buthotrephis lesquereuxii* described by Grote and Pitt from the Waterlime (Cobleskill) near Buffalo, N. Y."* White correlated the beds which furnished these plants with the "Round-out of Schuchert and Clarke.† (Cobleskill of the present N. Y. State Survey nomenclature.)

The species which Foerste has reported from the Kokomo limestone include one characteristic species of the Cobleskill dolomite of New York, *Spirifer corallinensis* Grabau, together with several which have their nearest allies in Salina or Cobleskill species. One of the ostracods Foerste finds closely related to *Isochilina grandis latimarginata*, a species which in Manitoba occurs above the gypsum beds which are believed to be of Salina age. The other ostracod in the Kokomo fauna Foerste finds closely related to a Decker Ferry species. Foerste's study of the fauna leads him to conclude that the Eurypterid horizon and probably the brachiopod horizon are of Salina age.‡

The absolute unlikeness of the Kokomo fauna and the faunas of the closely adjacent exposures of the Noblesville and Hunt-

* Proc. U. S. Natl. Mus., vol. xxiv, p. 267, 1905. † Ibid., p. 265.

‡ Jour. Cin. Soc. Nat. Hist., vol. xxi, p. 6, 1909.

ington formations appears to afford no grounds for their correlation. The presence in the Kokomo fauna, on the other hand, of species which are represented by identical or nearly allied species in the Salina or Cobleskill indicates that it represents either a Salina or Cobleskill horizon.

The eurypterids appear to afford no direct evidence concerning the age of the beds since none of the Kokomo species have been recognized outside the Kokomo district by Clarke and Ruedemann. One of the Kokomo species however is closely enough allied to *Eurypterus lacustris* of the Bertie waterlime to have lead Professor Claypole* to cite this species from the Kokomo limestone. Clarke and Ruedemann recognized in *Drepanopterus* characters which they suppose to be ancestral to those of certain New York Salina eurypterids. Phylogenetic evidence will undoubtedly become of increasing value in correlation as our knowledge of the history of biologic groups increases in completeness. But in the present state of our knowledge of the very imperfectly known Eurypterida this kind of evidence cannot be given much weight when, as already pointed out, it is opposed by direct evidence. The absence from the Kokomo eurypterid fauna, according to Clarke and Ruedemann, of any species common to it and any of the well known eurypterid horizons above the Lockport in the Silurian of New York, suggests a lack of identity between the Kokomo and any one of these horizons. It however affords no evidence that the Kokomo fauna does not represent a horizon intermediate between some two of these. It is a striking fact that but one of the twenty-nine species of eurypterids recorded from the five Silurian eurypterid horizons above the Lockport is known above or below the particular horizon in which it was discovered. Hence we cannot reasonably expect a distinct but closely related horizon, such as the Kokomo is believed to be, to contain species identical with any of the New York eurypterid horizons. In the writer's opinion, the Kokomo Eurypterid fauna represents a horizon of Salina age which is as yet faunally unknown in New York.

* Am. Geol., vol. vi, p. 259, 1890.

ART. XXVIII.—*Two Vanadiferous Ægirites from Libby, Montana*;* by ESPER S. LARSEN and W. F. HUNT.

INTRODUCTION.

THE two pyroxenes described in this paper were collected by Mr. J. T. Pardee of the United States Geological Survey in the Rainy Creek mining district, about 7 miles northeast of Libby, Lincoln County, Montana. Later Mr. Ben. M. Thomas, of Libby, Montana, sent the authors more material. We are indebted to these gentlemen for the excellent specimens and for information about the occurrence of the minerals.

The two minerals, one of which is an ægirite and the other an ægirite-augite, occur in veins associated with quartz, calcite, microcline, sulphides, and other minerals. The ægirite carries nearly 4 per cent of V_2O_5 , but otherwise its chemical composition is that of ordinary ægirite. The crystal measurements are also in close agreement with those of ægirite; the form *i* [130] is new for ægirite. The mineral is deep brown in color and its optical properties differ from the ægirite generally described in the lower index of refraction, weaker birefringence, smaller extinction angle, and larger axial angle. The ægirite-augite was found only in fibrous aggregates. It carries nearly 3 per cent of V_2O_5 and its optical properties are not greatly different from those of ordinary ægirite-augite.

Occurrence and associations.—The two pyroxenes occur together in veins which were probably formed under deep-seated conditions and at a high temperature. Indeed, they have some resemblance to pegmatites. White to milky, granular quartz is the most abundant mineral of the veins; calcite, the pyroxene and microcline feldspar are abundant; pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, and other sulphides, are less abundant; fluorite is present; and barite was recognized in one specimen. The veins show rather prominent banding, as the pyroxene and microcline are largely confined to their borders. The parts of the vein which are rich in either pyroxene are commonly also rich in microcline and sulphides.

The veins occur in a rather coarse-grained apatite-pyroxenite which is chiefly diopside with about 10 per cent of apatite, nearly as much titaniferous magnetite, and less biotite. This rock carries 0.12 per cent V_2O_5 . Associated with it are sodasyenites and nepheline-syenites. On each side of the veins the pyroxenite is altered for a distance of from an inch to a

* Published by permission of the Director of the United States Geological Survey.

foot or more. In the characteristic alteration the apatite, ore, and biotite are not changed, but the pyroxene is altered to a fibrous aggregate of amphiboles with calcite and sulphides. The amphibole has unusual and somewhat variable optical properties. Some of the deeper-colored parts resemble glaucophane, but the most common type has the following optical properties: The indices of refraction are $a = 1.620 \pm 0.003$, $\gamma = 1.630 \pm 0.003$. The birefringence is rather weak. Sections cut parallel to the side pinacoid do not extinguish in white light, but on revolving on the stage of the microscope they show a succession of abnormal interference colors. In monochromatic light this section showed the following extinction angles:

For Li—light	X	\wedge	$c = 45^\circ$
“ Na	“	X	\wedge $c = 41^\circ$
“ Th	“	X	\wedge $c = 35^\circ$

Z is parallel to c . The pleochroism is moderate: Z = pale-blue or pale-violet, Y = pale-yellowish, X = pale-green.

VANADIFEROUS *ÆGIRITE*.

The vanadiferous *ægirite* occurs chiefly near the borders of the veins, but it is not entirely confined to the borders. It commonly is in rather well-developed acicular crystals or fibrous aggregates oriented nearly normal to the walls of the vein. In other specimens beautiful spherulites of the mineral, up to an inch across, are scattered rather thickly in the vein material. These spherulites are made up of well-formed acicular crystals of the *ægirite* about a millimeter in cross section radiating from a common center and piercing the other minerals. One specimen shows fairly well-formed crystals several millimeters in diameter. The tendency of the *ægirite* to form well-bounded, prismatic crystals is marked. The thin sections show that the *ægirite* pierces the other minerals of the veins and especially the quartz; one individual may cross several quartz grains. Such crystals are commonly skeleton-like with a more or less continuous shell and several ragged strips between. Nearly all of the individuals show intergrown quartz; a few show, in addition, included sulphides. In other respects they are clear and free from inclusions.

Crystallography.—Although the bulk of the material is unsuitable for accurate goniometric measurements, after a careful search about two dozen more or less perfectly developed crystals were isolated and their examination led to the identification of six forms of simple indices. Crystals of two distinct types of development are represented. Figure 1 illustrates the short prismatic type with the positive hemi-orthodome as

an end termination. Crystals of this habit were generally noted in compact columnar intergrowths. The second type, which is shown in figure 2, is decidedly needle-like in character with broken ends. It is characteristic of the crystals in the spherulitic aggregates. In both types the unit prism is the predominant form in the vertical zone which emphasizes the quadratic cross section. The clino- and ortho-prisms as well as the corresponding pinacoids are extremely small. The reflec-

FIG. 1

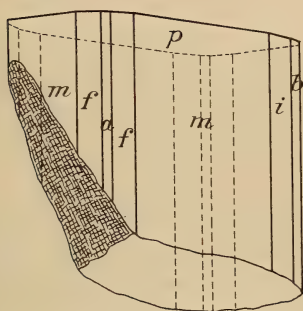
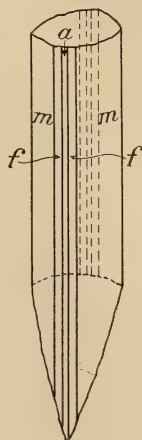


FIG. 2.



tions obtained were, for the most part, far from ideal, the larger prism faces showing multiple images as a result of vertical striations, while to obtain a sharp reflection from the orthodome a small piece of cover glass was cemented to the rather large but non-reflecting surface. In spite of these physical imperfections the close agreement between the average of a large number of observed readings with the corresponding values reported for ægirite by Brögger* leaves no doubt whatever as to the identity of the forms given in Table I. In this table under "Observed" are given the angles measured by Hunt on the vanadiferous ægirite from Montana and in the following column are given the corresponding angles measured by Brögger on ægirite from Norway.

Of the forms listed below the only one which has not previously been reported on ægirite is the clinoprism i [130]. It was found only on those crystals showing the short prismatic development (fig. 1). While apparently new for ægirite, it has

* Brögger, W. C., Zeitschr. f. Kryst., vol. xvi, p. 319, 1890.

TABLE I.
Crystal Angle of *Ægirite*.

	Observed	Brögger
$m : m = (110) : (\bar{1}10) =$	87° 5'	87° 11'
$m : a = (110) : (100) =$	46 29	46 24 1/2
$m : b = (110) : (010) =$	43 39	43 35 1/2
$f : f = (310) : (3\bar{1}0) =$	38 47	38 36
$f : a = (310) : (100) =$	19 7	19 18
$f : m = (310) : (110) =$	27 9	27 7
$i : i = (130) : (\bar{1}30) =$	35 58	— —
$p : m = (\bar{1}01) : (110) =$	100 33	100 19
$p : a = (\bar{1}01) : (\bar{1}00) =$	75 38	74 56

frequently been recognized on the diopside-augite series, where the corresponding angle is 35° 12'. This is of some interest as it will be shown that chemically the composition can be so interpreted as to show the presence of a considerable amount of diopside.

Physical properties.—The prismatic cleavages are very perfect—more perfect than is usual in *ægirite*. The hardness is about equal to that of ordinary *ægirite*, 6–6.5; the specific gravity as determined by the pycnometer method is 3.55. The mineral is rather strongly magnetic as small fragments of it are sensibly affected by an ordinary pocket magnet. The crystals are bright and lustrous; the color is nearly black in thick crystals, but thin splinters are brown and translucent.

Optical properties.—The optical properties of this *ægirite* closely resemble those of the *ægirite* from Langesund described by Brögger. The brown color is more prominent. It differs from other *ægirite* described in the lower index of refraction, weaker birefringence, smaller extinction angle, larger axial angle, and marked brown color. In the following table the principal optical properties of the vanadiferous *ægirite* from Libby, Montana, are given in column 1, and for comparison the data of Brögger on *ægirite* from Langesund, and that of Wülfing on *ægirite* from Langesund are given:

TABLE II.
Optical Properties of *Ægirite*.

Larsen Libby, Mont.	Brögger Langesund	Wülfing Langesund
$\alpha = 1.745 \pm 0.005$		1.7630 _y
$\beta = 1.770 \pm 0.005$	1.753 _y	1.7990 _y
$\gamma = 1.782 \pm 0.005$		1.8126 _y
$\gamma - \alpha = 0.034 \pm 0.002$		0.0496
$2V = 69^\circ \pm 3^\circ$	63°28' _y	62°13' _y
$X \wedge c = 1.4^\circ_y \pm 0.3^\circ$	2½° to 3½° _y	4° to 4°15' _y

The indices of refraction of the Montana mineral, determined by the oil-immersion method, vary somewhat and the values given are about the average. The birefringence was measured directly with a Babinet compensator. The value of $\gamma\text{-}\beta$ was found to be 0.011. Direct measurements of the axial angle were not satisfactory, but from the values of the birefringence it was computed to be $69^\circ \pm 3^\circ$. The dispersion of the optic axes is strong and $\rho > \nu$, as in ordinary ægirite. The extinction on the side pinacoid gave for an average of eight measurements in sodium light 1.4° , for an average of ten measurements in white light 1.2° . The color and pleochroism of the ægirite from Libby are its most marked characteristics. The pleochroism is strong: X is dark-brown, Y is lighter-brown, and Z is pale-yellowish brown or amber.

Chemical properties.—The material for analyses was first carefully picked out by hand and was later separated from the small amount of admixed quartz, microcline, calcite, and pyrite, by a weak electro-magnet. The resulting material was found on microscopic examination to contain a very small amount of impurity.

From a chemical standpoint the chief interest centers about the relatively high content of vanadium. Hillebrand* has called attention to the presence of vanadium in basic igneous rocks (under 60 per cent SiO_2), where as V_2O_5 it replaces alumina and ferric oxide in pyroxene, hornblende, and biotites. In these instances, however, its presence is usually recorded as a few hundredths of one per cent. In one case, that of a biotite separated from a pyroxenic gneiss, the vanadium content was somewhat higher, reaching .13 per cent V_2O_5 . In the roscoelite mica the content of V_2O_5 is much higher. It would seem from this that the content of vanadium in mafic minerals other than mica rarely exceeds two-tenths of one per cent. The two minerals here described were unusual in this respect: in one specimen the vanadium oxide was present to the extent of almost 1 per cent, while the second showed a slightly smaller amount.

Table 2 gives the chemical analyses of ægirite from Libby, Montana, by Hunt, and from Brevig by Doelter;† the two analyses show a somewhat close similarity. In the latter case TiO_2 was absent and V_2O_5 either absent or else not sought for.

Columns 1 and 2 of Table 3 give the molecular ratios corresponding to the analyses of the Montana ægirite. If we deduct from this the equivalent of $\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2$ (acmite)

* Hillebrand, W. F.: The analysis of silicate and carbonate rocks: Bull. U. S. Geol. Survey, No. 422, pp. 20, 24, 149, 1910.

† Doelter, Tscherm. Mitth., vol. i, p. 376, 1878; also in Zeitschr. f. Kryst., vol. iv, p. 91.

TABLE III. Analyses of Ægirite.

	Doelter	Hunt
SiO ₂	51.74	51.91
TiO ₂ .....		.91
Fe ₂ O ₃	26.17	21.79
V ₂ O ₃		3.98*
Al ₂ O ₃ .....	.47	.38
CaO	5.07	5.53
MgO	1.79	3.08
FeO	3.48	1.48
MnO .....	.46	.58
Na ₂ O	11.02	10.46
K ₂ O .....	.34	.22
<hr/>		
H ₂ O —	100.54	.06
H ₂ O +		none
S .....		.13
CO ₂		trace
		<hr/>
		100.51

shown in column 3 there remains the molecular proportions given in column 4, which closely approximates CaO.MgO.2SiO₂ (diopside).

	1	2	3	4
SiO ₂8608	.8721	.6840	.1881
TiO ₂ .....	.0113		
Fe ₂ O ₃ .....	.1364		
V ₂ O ₃ .....	.0264		
Al ₂ O ₃ .....	.0037		
CaO0986	.0986	.1710	.0986
MgO .....	.0763		
FeO .....	.0206		
MnO .....	.0081		
Na ₂ O .....	.1687		
K ₂ O0023	.1710	.1710	

These figures correspond to an isomorphous mixture of about 73 per cent of ægirite, where the K₂O replaces the Na₂O, V₂O₃ and Al₂O₃ the Fe₂O₃, TiO₂ the SiO₂; and 27 per cent diopside, where the MgO is replaced in part by FeO and MnO. A comparison of the analysis with that calculated containing 73 per cent Na₂Fe₂Si₄O₁₂, and 27 per cent CaMg(SiO₃)₂ shows:

* A duplicate sample gave 3.81 per cent.

	Analyses	Calculated
SiO ₂ (+ TiO ₂)-----	52.82	52.94
Fe ₂ O ₃ (+ V ₂ O ₅ + Al ₂ O ₃)--	26.15	25.26
CaO -----	5.53	7.00
MgO (+ FeO + MnO)-----	5.14	5.00
Na ₂ O (+ K ₂ O) -----	10.68	9.80

While there is a slight variation, the agreement is sufficiently close to warrant the suggestion.

VANADIFEROUS ÆGIRITE-AUGITE.

The vanadiferous ægirite-augite is from the same locality as the ægirite and is closely associated with the microcline-rich portions of the veins. It is present in spherulites of radiating fibers up to an inch across. These spherulites are commonly, nearly pure pyroxene; along their border the pyroxene needles pierce the grains of microcline, quartz, and calcite. The fibers are very small and are closely packed so that no material was available for crystal measurements and even the cleavage angle could not be determined under the microscope.

Optical properties.—The pyroxene is grayish green in color. Its finely fibrous character made accurate optical measurements impossible, but its optical properties do not differ greatly from those of ordinary ægirite-augite. The indices of refraction as measured by the immersion method are $a = 1.720 \pm 0.003$, $\gamma = 1.747 \pm 0.003$. The axial angle is large, and the extinction on cleavage fragments is about 20° ($X \wedge c$). The maximum extinction in the section was 24° . The pleochroism is rather strong: X = light-green, Y = greenish yellow, and Z = pale-yellow. The specific gravity is 3.42.

Chemical properties.—Material for the chemical analyses was carefully selected and the analyses yielded the following results:

		Mol. ratio	
SiO ₂ -----	53.32	.8842	} .8889
TiO ₂ -----	.38	.0047	
Fe ₂ O ₃ -----	12.38	.0770	
V ₂ O ₅ -----	2.86*	.0190	} .1097
Al ₂ O ₃ -----	1.40	.0137	
CaO-----	12.18	.2171	
MgO-----	7.01	.1738	} .2315
FeO-----	3.70	.0514	
MnO-----	.45	.0063	
Na ₂ O-----	6.26	.1009	} .1036
K ₂ O-----	.26	.0027	
<hr/>			
Cr ₂ O ₃ -----	trace	1.5508	
H ₂ O-----	.07		
H ₂ O +-----	.13		

100.40

* A duplicate sample gave 2.82 per cent.

If we deduct from the molecular ratios given above the equivalent of ægirite, namely, Na_2O , Fe_2O_3 , 4SiO_2 , as follows :

$\text{Na}_2\text{O} + \text{K}_2\text{O}$	·1097	
$\text{Fe}_2\text{O}_3(+ \text{V}_2\text{O}_3 + \text{Al}_2\text{O}_3)$	·1097	
$\text{SiO}_2(+ \text{TiO}_2)$	·4388	
	<hr/>	·6582
There would remain		
$\text{SiO}_2(+ \text{TiO}_2)$	·4501	
CaO	·2171	
$\text{MgO}(+ \text{FeO} + \text{MnO})$	·2315	
	<hr/>	·8987
		<hr/>
		1·5569

As in the ægirite the constituents in the residue approximate diopside, CaO.MgO.2SiO_2 . In this case we are dealing with an isomorphous mixture of about 43 per cent ægirite and 57 per cent diopside. A comparison of the analysis with the calculated composition of such a pyroxene shows :

	Analysis	Calculated
$\text{SiO}_2(+ \text{TiO}_2)$	53·70	54·01
$\text{Fe}_2\text{O}_3(+ \text{V}_2\text{O}_3 + \text{Al}_2\text{O}_3)$	16·64	14·88
CaO	12·18	14·78
$\text{MgO}(+ \text{FeO} + \text{MnO})$	11·16	10·56
$\text{Na}_2\text{O}(+ \text{K}_2\text{O})$	6·52	5·77

ART. XXIX.—*A Method of Increasing and Controlling the Period in Vertical Motion Seismographs*; by FRANK A. PERRET.

IN order to obtain a satisfactory period of vibration in seismographs for recording vertical motion, the designers of such instruments are generally under the necessity of employing, for the suspension of the weight, a long and sensitive spring under strong tension. The use of such a spring, however, introduces a very serious defect in the practical working of the instrument, viz. a lack of stability in the position of rest due to the effect upon the spring of variations of temperature. The result is a continual wandering of the recording lever from its normally central position, creating a difficulty which the most ingenious of compensating devices have not, so far, been able to satisfactorily obviate. Furthermore, it is probable that, aside from the effect of temperature changes, a spring of such length and in so delicate a condition of balance will always be more or less subject to slight alterations which, magnified by the multiplying levers, cannot fail to be troublesome—the difficulty is *inherent in the large amount of spring* ordinarily required in this type of instrument.

It occurred to the writer that the variations of a magnetic field—due to relative motion of the parts of an instrument in action—might be utilized as a counter influence to the otherwise brusque action of a coarse and stiff spring, thus permitting the use of one so short and robust as to be free from extreme sensitiveness to temperature and other variations. From materials already at hand in the laboratory the crude apparatus shown in the figure was erected, it is scarcely necessary to say as an experimental instrument for testing the principle, and not, in any sense, as a model for eventual construction.

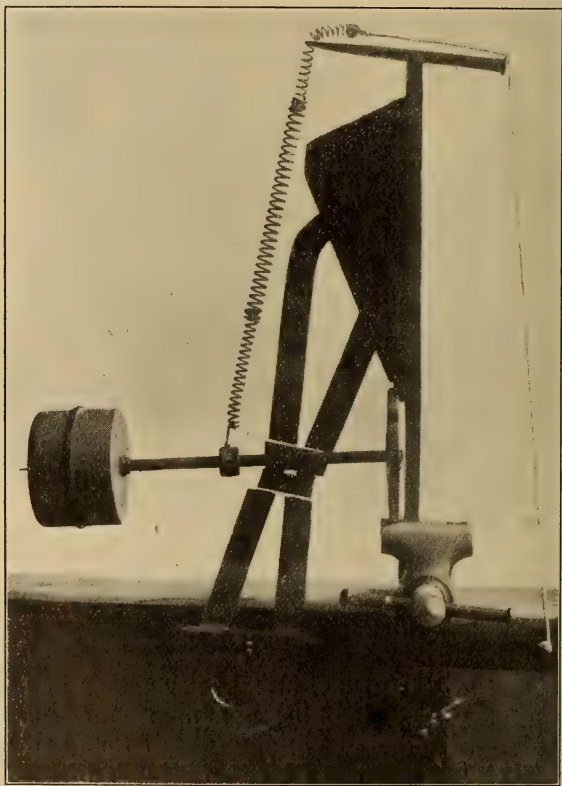
A horizontal lever of 20^{cm}, pivoted at one end and carrying at the other a weight of 2.5 kilos, is supported, as shown, by a stiff spring. The period of vibration is less than half a second and, once set in motion, the lever continues to oscillate for more than a minute, thus forming, it will be seen, an impossible instrument from the standpoint of modern requirements.

If two armatures are now mounted upon the lever and their relative magnets attached to the frame of the instrument above and below, as shown in the figure, the pull of the upper magnet is counterbalanced by the downpull of the lower one and, *statically*, the entire system is in precisely the same condition as before. If we now imagine a sudden upward movement, the weighted end of the lever, by its inertia and mode of sus-

pension, tends to remain at rest. But, unfortunately, this involves the stretching of the spring by which means the weight is lifted and set in vibration, and it is precisely for the minimizing of this effect that so long and sensitive a spring must ordinarily be provided.

In the present case, however, it will be seen that the relative motion of the different parts of the instrument has altered

FIG. 1.



the conditions in the magnetic field, the upper magnet receding from its armature, increasing the "entrefer" and decreasing the upward pull on the lever while, per contra, the lower "entrefer" has diminished, thus increasing the downward pull. These two effects combine, therefore, to offset and counteract the increased tension of the spring and they may be given any desired value in relation thereto. In the present

very small apparatus, and with the crudest of adjustments, the period was readily increased to from two to four seconds and could even—within narrow limits of movement—be made almost absolute, i. e., the instrument could be made aperiodic. The motion in the magnetic field produced a fair amount of damping, so that the application of this magnetic principle may be said to have converted an impossible instrument into one which, for its size, might be considered as a satisfactory vertical motion seismograph.

It will be seen that the magnetic apparatus used in this experiment was far from being well adapted to the purpose. The closeness together of the poles of the magnets gives an exceedingly restricted external field, necessitating the locating of the magnetic control near to the pivoted end of the lever instead of at the weighted end, where its efficiency would have been far greater. In the case of a heavy-weight seismograph a battery of long field magnets is indicated, with armatures possibly V-shaped to ensure diagonal approach, the magnetic system to be mounted on an outer extension from the weight for greater leverage. But the details of construction must be left to the manufacturer, who will adapt the magnetic auxiliary to the design of the instrument, the present paper being merely a presentation of the bare principle. It need scarcely be stated that the magnets should be of the best material, strongly charged and then ripened down to the point of permanence, and that their mounting should be provided with fine screw adjustments.

Anticipating a possible criticism, the writer would state that he cannot believe that any variations of terrestrial magnetism nor action of telluric currents at the time of an earthquake could adversely affect this appliance. Even supposing that these phenomena had the power to momentarily weaken or strengthen such powerful magnetic fields, both would be affected alike and the only effect upon the seismograph would be a difference in the ratio of the values of magnetic control and spring power. But the failure of even delicate apparatus designed to act as seismographs by magnetic variation, may serve as a sufficient guarantee of the integrity of powerful fields.

We have so far considered this magnetic control as applied solely to seismographs for vertical motion, and this for the reason that, on account of the spring suspension, it is here that the need is most apparent. But it is conceivable that, in many cases, a horizontal pendulum would be the better for a more positive self-centering factor in the pendulum *per se*, the period then being increased to any desired value by the magnetic control.

If it shall be found possible to obtain uniform action in all azimuths, the great length of the simple pendulum, now requiring a tower, might be reduced to the dimensions of an ordinary building, and this suggests a somewhat different application in the case of *inverted* pendulums, viz. to employ the *repulsive* action of *like* magnetic poles—uniformly spaced around the magnetized pendulum rod, or magnets mounted thereon—in lieu of springs, for the maintaining of this in its central position. Such an instrument—especially if provided with optical registration—would, by its freedom from mechanical contact with the static mass, closely approach the ideal.

The writer has not tried out these last forms experimentally and they are here given simply as constituting a natural line of thought from the first idea.

Posillipo, Naples, June 9, 1913.

ART. XXX.—*The Action of Sodium Paratungstate in Fusion on Salts of the Halogen Acids and Oxy-halogen Acids;*
by S. B. KUZIRIAN.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccxlvii.]

THE use of sodium paratungstate as a flux in the expulsion of carbon dioxide from carbonates and nitrogen pentoxide from nitrates has been proved to be sharp and complete.* It is likewise of interest to note the action of this flux on other common salts that have a volatile acid radical.

Salts of the Halogen Acids.

Sodium Fluoride and Silicofluoride.—When a mixture of 0.2 grm. of sodium fluoride with 3 grm. of sodium paratungstate is fused a partial elimination of chlorine takes place slowly. In one experiment the loss of fluorine after ten minutes' fusion amounted to about fifty per cent of that originally present in the fluoride.

On application of heat to a mixture of sodium silicofluoride and sodium paratungstate, gaseous silicon tetrafluoride is evolved, but this is immediately attacked by the atmospheric oxygen and water vapor from the source of heat and a white deposit of silica, which does not disappear on further ignition, is formed on the edges of platinum crucible.

Sodium Chloride.—The reaction between sodium chloride and sodium paratungstate is likewise slow and incomplete. For example, in one experiment it was found that a twenty-minutes' fusion of a mixture of 3 grm. of sodium paratungstate and 0.3 grm. of sodium chloride effected the decomposition of the chloride to an amount of only forty-six per cent, and on further heating the reaction proceeded even more slowly and could not be brought to completion with accuracy.

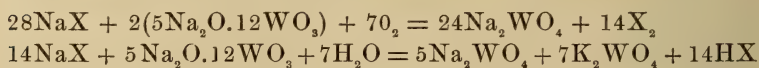
Sodium Bromide.—From the fact that the same conditions prevail in the fusion of bromides with paratungstate as in the case of chlorides, it is natural to expect that only partial decomposition will take place; and that is due, similarly, to the slow atmospheric action upon the fused mass. In ten minutes' fusion of a mixture of 3 grm. of sodium paratungstate and 0.3 grm. of sodium bromide, about sixty per cent of the bromide was decomposed, as against a forty-six per cent loss in twenty minutes' ignition in the case of sodium chloride. After this period the reaction began to proceed much more slowly.

Potassium Iodide.—The action of sodium paratungstate upon iodides is somewhat different from that upon the rest of

* This Journal [4], xxxi, 497.

halogen salts. The reaction proceeds to completion without any difficulty, and this flux seems to be capable of expelling the iodine completely from iodides in a gentle ignition of from five to ten minutes.

In the case of fluorides, chlorides, and bromides it appears that the action of sodium paratungstate in the expulsion of the halogen element from chlorides is not complete for the reason that the simple elimination of that element will not leave an oxide to combine with the acidic oxide of the flux. If the fusion with the flux were carried *in vacuo* or in an atmosphere free of oxygen there would probably be no marked decomposition. So the observed partial decomposition of the halogen salts with a slow evolution of the halogen is apparently due to the agency of atmospheric oxygen, or moisture, which may serve essentially the end of oxidizing the metal to a basic oxide which combines with the acidic tungstic oxide, thus helping in the expulsion of the halogen. This action, which may be represented by the following equation :



is slow and incomplete.

The complete decomposition of iodides with this flux can be accounted for by the higher susceptibility of these salts to atmospheric action.

The disappearance of the beautiful violet color of iodine is a fair indication of the completion of reaction. A wide-bottomed platinum crucible is advantageous in these determinations, on account of the large surface exposure of the contents to the atmospheric action. It is also desirable to shake gently the contents of the crucible when the end point is approached, thus giving a better chance for oxidation. The use of sodium paratungstate in the estimation of iodine in iodides is shown in the following table :

Analysis of C. P. KI of Commerce, after Drying.

No.	KI taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0.3000	2.	0.2170	0.2149	+ 0.0021
2	0.3000	2.	0.2155	0.2149	+ 0.0006
3	0.3000	2.	0.2154	0.2149	+ 0.0005
4	0.3000	2.	0.2156	0.2149	+ 0.0007
5	0.3000	2.	0.2157	0.2149	+ 0.0008
6	0.3000	2.	0.2148	0.2149	— 0.0001

The constancy of weight of the sodium paratungstate is to be tested from time to time by fusing and weighing over again. The iodide may be added to the cooled solid mass and ignited to expel iodine. The flame should be regulated to obviate undue violence of action, which may be a source of mechanical loss. A gentle ignition of from seven to ten minutes was sufficient to obtain the results in the above table.

It is of interest to note that with the use of this flux the decomposibility of the halogen salt (the fluoride being an exception) increases with rise in the atomic weight of the halogen. Thus iodine (with an atomic weight of 126.92) is completely expelled from iodides with the use of paratungstate. Bromine (with an atomic weight of 79.94) is decomposed to the extent of 60 per cent approximately. Chlorine (with an atomic weight of 35.46) is decomposed to the extent of 46 per cent approximately. According to this observation it would naturally be expected that fluorine (with an atomic weight of 19) would stand in its proper place, with a less degree of decomposition than chlorine; but instead, it stands between bromine and chlorine, being decomposable under similar conditions to the extent of 57 per cent approximately. It seems plausible, however, that the seemingly high susceptibility of the fluoride to atmospheric action was in reality due to the hygroscopic condition of the fluoride when it was submitted to the action of the paratungstate.

Salts of Oxy-halogen Acids.

The action of sodium paratungstate upon salts of the halogens having been shown to be incomplete, with the exception of iodides, it is interesting to note the action of the same flux upon some salts of oxy-halogen acids—namely, chlorates, perchlorates, bromates and iodates—in a state of fusion. In view of the varying facility with which chlorides, bromides and iodides, respectively, undergo decomposition, it is natural to expect, as proves to be the case, that the order of decomposition will be the same for the oxygen salts.

Under similar conditions of experimentation chlorates were decomposed to about 40 per cent, bromates to 67 per cent and iodates completely, in ten minutes' fusion. In the case of iodates, a fusion of from four to seven minutes proved to be sufficient to eliminate all the iodine.

In the process of fusion oxygen first begins to escape and the evolution of halogen is rapid. When the oxygen of the salt has all been expelled, the reaction proceeds very slowly, as it has to depend upon the atmospheric oxygen or moisture to do the work. The experimental tests showed that neither

chlorine of the chlorate nor the bromine of the bromate was expelled under the analytical conditions within a reasonable time; while a five-minute fusion, carried out with extreme care to avoid mechanical loss, was sufficient to effect the elimination of iodine from the iodate.

The use of sodium paratungstate in the estimation of iodine and oxygen in iodates is shown in the following table:

Analysis of C. P. Potassium Iodate of Commerce after Drying.

No.	KIO ₃ taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0.3000	2.	0.2335	0.2339	+ 0.0004
2	0.3000	2.	0.2335	0.2339	+ 0.0004
3	0.3000	2.	0.2330	0.2339	+ 0.0009
4	0.3000	2.	0.2330	0.2339	+ 0.0009

It is advantageous to heat the platinum crucible by waving under it a small flame, thus obviating undue violence of action.

ART. XXXI.—*The Use of the Sodium Paratungstate and the Blowpipe Flame in the Determination of the Acid Radicals of Chlorides, Chlorates, Perchlorates, Bromides, Bromates and Fluorides*; by S. B. KUZIRIAN.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccxlviii.]

Introductory.

THE ability of sodium paratungstate to decompose and expel the volatile acid radicals from certain salts like carbonates, nitrates, iodides and iodates has been shown in a previous paper.* It has also been shown that the action upon chlorides, chlorates, bromides, bromates and fluorides under ordinary atmospheric conditions is only partial.† Under such conditions only certain portions of the salts are broken up and the reactions then become very slow.

The imperfection of the reaction can be accounted for in the case of chlorides and bromides by the fact that these compounds do not contain a basic metallic oxide to unite with the acidic tungsten trioxide, and therefore have to depend upon the gradual action of atmospheric oxygen or moisture to produce a decomposition which is so slow that the reaction cannot be completed within a reasonable time. The results are, however, sharp and accurate in the case of carbonates and nitrates, which are composed of a basic oxide and an easily volatilizable acidic oxide. Chlorates and bromates, having a molecular constitution similar to that of nitrates, might be expected to behave similarly on treatment with sodium paratungstate. But on the fusion of potassium chlorate with this flux, the oxygen of the chlorate does not form potassium oxide, while oxygen is liberated before the salt actually begins to be acted upon by the paratungstate, leaving potassium chloride. Bromates being unstable like chlorates behave exactly in the same way on similar treatment with the paratungstate. Oxygen is evolved and a bromide is left. So, for the same reason, the expulsion of the halogens from chlorates and bromates is only partial, and the degree in which the halogen is eliminated proves to be almost the same for the same duration of fusion as with chlorides and bromides.

Having in view the function of atmospheric oxygen and moisture in partial decomposition of chlorides, bromides, fluorides, chlorates and bromates, it was natural to look for a reagent which would accomplish the decomposition more efficiently by supplying oxygen while removing the halogen.

* This Journal [4], xxxi, 497.

† Ibid., xxxvi, 301.

Superheated steam was found to be the reagent desired. Steam in a superheated state attacks the chlorides and bromides. From sodium chloride and sodium bromide, for example, a metallic oxide is formed and hydrochloric acid and hydrobromic acid are evolved. The inconvenience of this reaction is that at sufficiently high temperature the alkali oxide, as well as halogen acids, are volatile, and their products tend to combine again to form NaCl and NaBr. If this reaction takes place in presence of fused sodium paratungstate, the tungsten trioxide will take up the metallic oxide and the acid formed is quickly expelled.

The reaction between steam, sodium paratungstate and sodium chloride may be represented as follow:



In preliminary tests the following procedure was used. The steam was led from a flask through a platinum tube to the crucible which contained the fused mass of sodium paratungstate and sodium chloride. The platinum tube was heated to redness, the steam passing through the red hot platinum tube became superheated, and the interaction between the steam and the chloride resulted in the immediate evolution of hydrochloric acid.

The same effect may be brought about more conveniently and with great accuracy by directing a sharp, thin blowpipe flame upon the surface of the fused mass of sodium paratungstate and chloride, since superheated steam is one of the principle combustion products of illuminating gas. The gaseous carbon dioxide formed in the interaction is completely expelled from the fused mass by the acidic tungstate, as shown in the determination of carbonates, and the water vapor formed is superheated and ready to take part in the reaction. The thin, sharp blowpipe flame serves excellently the double object of keeping the mass in quiet fusion and of furnishing superheated steam to bring about the desired effect.

The procedure is as follows: A 20-gram platinum crucible is weighed, and a specified amount of sodium paratungstate is introduced, fused with a small sharp blowpipe flame from above and kept in fusion for five minutes in order to expel by the action of steam at high temperature any impurities (e. g. chlorine of chlorides) volatile under the conditions. The crucible and contents are cooled and weighed. Next a weighed amount of the salt to be analyzed is introduced, and the material in the crucible is carefully fused with the gentle heat of a burner with care to avoid spattering. Then a very small and sharp flame of the blowpipe is directed upon the surface of the

fused mass for a period of five to eight minutes, until a constant weight is obtained.

The whole determination can be accomplished in a comparatively short time.

Sodium chloride.—In the table are given the results which were obtained by the action of superheated steam upon the fused mass of sodium paratungstate and sodium chloride, under the conditions specified.

TABLE I.

Analysis of C. P. Sodium Chloride, after Drying.

No.	NaCl taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0.2000	2	0.0936	0.0940	—0.0004
2	0.2000	2	0.0938	0.0940	—0.0002
3	0.2000	2	0.0938	0.0940	—0.0002
4	0.2000	2	0.0933	0.0940	—0.0007

Sodium chloride being an extremely stable salt, a prolonged ignition of fifteen to twenty minutes was necessary. It was customary to weigh after each period of five minutes' ignition with the blowpipe, in the manner already specified. The residue was tested for chlorine with chromic anhydride test* which is sensitive to about 0.5 mg. of chloride. No indication of chlorine was found.

Potassium chlorate.—Table II shows the results obtained when the sodium paratungstate was fused with potassium chlorate in the manner already specified, care being taken to expel volatile material slowly, thus avoiding possible mechanical loss of material due to violent evolution of oxygen. This was accomplished by applying a gentle heat of a Bunsen burner from beneath the platinum crucible, until quiet fusion took place. Then a small blowpipe flame was applied in the manner described.

TABLE II.

Analysis of C. P. Potassium Chlorate of Commerce, after Drying.

No.	KClO ₃ taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
{ 1	0.2000	2	0.1241	0.1231	+0.0010
{ 2	0.2000	2	0.1260	0.1231	+0.0029
3	0.2000	2	0.1230	0.1231	—0.0001
4	0.2000	2	0.1233	0.1231	+0.0002
5	0.2000	2	0.1233	0.1231	+0.0002
6	0.2000	2	0.1237	0.1231	+0.0006

* Gooch and Brooks, this Journal (3), xi, 283.

In determinations Nos. 1 and 2, the mixtures were ignited with the blowpipe flame for nine minutes without first bringing the mixture to quiet fusion with a Bunsen flame and the large positive errors are without doubt due to the consequent mechanical losses. Nos. 3, 4, 5, and 6 were subjected to the blowpipe flame for seven minutes, after observing all the precautions. A chlorochromic anhydride test of the residue failed to give any indication of chlorine. It is curious to note that the expulsion of volatile matter is accomplished in the case of a chlorate in a shorter time than with chlorides, a fact which can be accounted for upon the assumption that the oxygen of the chlorate is not all liberated in the first stage of reaction, but it remains partially to take part in the interaction, thus shortening the necessary duration of the blast ignition.

Sodium bromide.—The decomposition of bromides with the expulsion of the volatile acid radical is achieved with more ease than that of chlorides. As previously shown, the tendency toward decomposition increases with the rise in the atomic weight of the halogen.

Following are some of the results obtained when C. P. sodium bromide was acted upon with the flux in presence of steam produced in the blowpipe flame directed from above upon the mixture :

TABLE III.

Analysis of C. P. Sodium Bromide of Commerce, after Drying.

No.	NaBr taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0.1932	2	0.1354	0.1350	+0.0004
2	0.2000	2	0.1397	0.1398	—0.0001
3	0.2000	2	0.1397	0.1398	—0.0007
4	0.2000	2	0.1392	0.1398	—0.0006

The actual and theoretical losses agree within the range of experimental error. The average duration of ignition was about nine minutes.

All the precautions applicable in the case of chlorides are applied in the treatment of bromides.

Potassium bromate.—The analysis of potassium bromate was carried under the same conditions, with all the precautions that were applied to chlorates. The results obtained are shown in Table IV.

The average duration of ignition in the above determination was twelve to fifteen minutes.

Potassium perchlorate.—In the description of the analysis of chlorates with the use of sodium paratungstate, it was shown,

TABLE IV.

Analysis of C. P. Potassium Bromate of Commerce, after Drying in the Air Bath.

No.	KBrO ₃ taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0.2000	2	0.1437	0.1436	+0.0001
2	0.2000	2	0.1430	0.1436	—0.0006
3	0.2000	2	0.1440	0.1436	+0.0004
4	0.2000	2	0.1446	0.1436	+0.0010

that the decomposition was effected in two stages, most of the oxygen being liberated in the first stage of the reaction; a small portion of it, together with the superheated steam, would act upon the fused mass of the mixture of paratungstate and chlorate, and complete decomposition would ensue, with liberation of its volatile acid radical. In connection with this, it was also mentioned that, probably due to the part played by this small portion of chlorate oxygen, the duration of blast ignition was greatly shortened. Perchlorates (e. g. potassium perchlorate) being richer in oxygen than chlorates while the temperature of dissociation is higher, it would be expected that the part played by the oxygen in this substance would be even more pronounced than in the case of chlorates, and so it is in fact. A complete decomposition of the perchlorate could be brought about within five moments with the use of this flux and superheated steam, under conditions specified. For the amount of substance taken the necessary duration of blast ignition in the case of chlorides is from fifteen to twenty minutes, in chlorates from seven to ten minutes, whereas five minutes will suffice in the case of perchlorates. The rapid interaction of perchlorates with the paratungstates is not altogether chargeable to the extra atom of oxygen which the perchlorate has over the chlorate. When the quantity of oxygen present in chlorates and perchlorates is the only agency to effect their decomposition, there should not be such a marked difference in the duration of blast ignition, as there is more than enough oxygen in the case of chlorates as well as in perchlorates. The higher temperature of dissociation of the perchlorate appears to favor the reaction between the oxygen and the chloride. Perchlorates, unlike chlorates, being more stable do not lose their oxygen in the first stage of reaction, but retain it until thorough decomposition begins. Then the oxygen liberated simultaneously, while the reaction is proceeding, will certainly take part in the interaction, thus shortening the process to a great extent. Another important point well worth mentioning in this connection, is that the

melting points of potassium perchlorate and sodium paratungstate are rather near to each other. First the perchlorate melts, and then the paratungstate begins to fuse, with rather a violent interaction, so excessive care is necessary to avoid mechanical loss at this point.* After the violent action ceases then the cover of the platinum crucible is taken off, and the usual blast ignition started.

The potassium perchlorate used in the analysis was the C. P. material of Commerce containing 1·8 per cent potassium chlorate as impurity. Results obtained with this potassium perchlorate are shown in Table V.

TABLE V.

Analysis of Potassium Perchlorate of Commerce, after Drying in the Air Bath.

No.	KClO ₄ taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0·3055	3	0·1996	0·2000	—0·0004
2	0·3055	3	0·2004	0·2000	+0·0004
3	0·3055	3	0·2015	0·2000	+0·0015
4	0·3055	3	0·2006	0·2000	+0·0006
5	0·3055	3	0·2015	0·2000	+0·0015
6	0·3055	3	0·2000	0·2000	0·0000

After bringing the mixture of perchlorate and paratungstate to quiet fusion with a gentle flame of the Bunsen burner waved underneath the platinum crucible, from three to five minutes' blast ignition sufficed to obtain the results in the table. The reason for choosing a rather odd amount of perchlorate for analysis was because it contained 1·8 per cent potassium chloride and the amount taken in each determination corresponds exactly to 0·3000 gram. of the perchlorate. Analysis of hypo salts of halogens was not attempted because of their indefinite composition and the difficulties with which they can be isolated.

Fluorides.

The observation that the tendency of the halogen salts to decompose when heated in the atmosphere increases as the atomic weight of the halogen rises, does not hold in the case of fluorine. The atomic weight of fluorine, being the lowest among the halogen atomic weights, it would be expected that this element would show the lowest tendency to decompose; but in this respect it ranks almost with bromine, and is much above chlorine. But this may be due to the greater hygro-

* Precautions to be observed under such conditions have been described in connection with the chlorates and bromates.

scopicity of the fluoride, and the consequently greater part played by water in ignition.

In expelling fluorine from fluorides, with the use of the blowpipe flame, free hydrofluoric acid is evolved, and so the determinations must be carried out under a good draft hood. Being slightly volatile, sodium fluoride may, on ignition with the paratungstate, escape somewhat as such, unless steps be taken to prevent loss by carefully moderating the heat. The author's method of overcoming this source of error is, to cover the bottom of the platinum crucible with paratungstate, to add the fluoride and cover it with another weighed portion of sodium paratungstate, to fuse with a very gentle flame of the Bunsen burner, and then to apply the usual blowpipe flame. The covering layer of paratungstate serves as a trap to hold back the somewhat volatile fluoride.

The paratungstate used must, of course, be free from material volatile in the ignition, and this condition is easily fulfilled by subjecting the paratungstate to a preliminary ignition in the superheated steam of the blowpipe flame directed upon it from above. The expulsion of the volatile halogen from a fluoride can be completed within less than five minutes.

In Table VI are given the results of the estimation of fluorine in sodium fluoride.

TABLE VI.

Analysis of C. P. Sodium Fluoride of Commerce, after Drying.

No.	NaF taken gram.	Na ₁₀ W ₁₂ O ₄₁ taken gram.	Loss on ignition gram.	Theory for loss gram.	Error gram.
1	0.2000	3	0.0531	0.0524	—0.0007
2	0.2000	3	0.0531	0.0524	—0.0007
3	0.2000	3	0.0522	0.0524	+0.0002
4	0.2000	3	0.0526	0.0524	—0.0002
5	0.2000	3	0.0528	0.0524	—0.0004

Summary.

Sodium paratungstate of the composition $5\text{Na}_2\text{O} \cdot 12\text{WO}_3$, an acidic salt capable of combining with metallic oxides in a state of fusion to form tungstates with the quantitative expulsion of certain volatile acid radicals, is easily prepared by fusing sodium tungstate with an equal weight of tungsten trioxide, the acidic salt thus formed being readily fusible, and not volatile under the conditions of this work. It is not more than ordinarily hygroscopic and can easily be kept dry in a desiccator over sulphuric acid. The duration of ignition is remarkably short, as compared with the time required in the case of other fluxes

thus far proposed. It has been previously shown (loc. cit.) that the determinations of the acidic element or oxide of carbonates, nitrates, iodides and iodates can be made with great accuracy by simple fusion made in the ordinary way. The present paper shows that the process may be extended to the analysis of chlorides, chlorates, perchlorates, bromides, bromates, and fluorides, if the precaution be taken to make the fusion in the presence of superheated steam produced in the direct application of the blowpipe flame to the paratungstate mixture.

In view of the experience detailed it is plain that the properties of sodium paratungstate make it an excellent and a very handy reagent for use in the analytical laboratory.

SCIENTIFIC INTELLIGENCE.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Atlas der Krystallformen*; von VICTOR GOLDSCHMIDT. Volume I, in two parts, Adamin-Buntkupferez: Atlas, plates 1-244; Text, pp. vi, 248. Heidelberg, 1913 (Carl Winters Universitätsbuchhandlung).—The prospectus of the Atlas of Professor Goldschmidt was noticed at length in the May number of the Journal. Since then the first volume of this great work has been distributed and the promises of the preliminary announcement are more than fulfilled in it. This volume is in two parts: the first is devoted to an Atlas of two hundred and forty-four plates embracing all the mineral species included under the letters A and B. The accompanying volume of text gives the information which is needed to make the plates intelligible. The list of forms is presented after the manner of the well-known Index of the author and the literature citations are as complete as could be desired.

In the preface to the text the author explains the broad standpoint from which he has been led to develop this work, desiring to bring together the material which shall be available for solving many of the problems of crystals and their growth, particularly with respect to the crystal habit, the frequency of occurrence of certain forms and the relative size of the faces. The author's earlier labors in similar fields, as also his extraordinary power for carrying through complex and difficult investigations, fit him peculiarly for a task of this magnitude. The completeness with which the subject is handled will be appreciated from the fact that the single species barite is represented by 737 figures, anglesite by 460 and aragonite by 302; while the monoclinic amphiboles, apatite, axinite, beryl and bournonite have each from 160 to 186 figures. The reproduction of the figures by the engraver is excellent and the author has shown rare good judgment in taking these figures direct from the original authors without attempting the enormous task of redrawing. The latter plan must, of necessity, have resulted in another elegant fragment, as that of Schrauf, while now we may hope, with the author, that his task may be completed by the publication of four or five additional double volumes, one for each year succeeding the present. No student of mineralogy can afford to be without a work of this importance and completeness.

2. *Dybdeboring i Grøndals eng ved København 1894-1907 og dens videnskabelige Resultater*; ved E. P. BONNESEN, O. B. BÖGGILD og J. P. RAVN. Pp. 106, pls. 8. Udgivet paa Carlsbergfondets bekostning. Copenhagen, 1913.—This volume gives the record of a boring carried to a depth of 2742 feet, 860.6 meters, near Copenhagen. Its depth is much greater than any other boring in the region, and its vicinity to Copenhagen enabled

an exceptional amount of study to be given to it by the professors resident there. The first part is given up to the records of the boring, including a full description of the methods. The temperatures were taken at numerous intervals and show a rectilinear temperature gradient of 21.5° per kilometer, beginning with 8.3° at the surface. The rocks penetrated are limestones of the Upper Cretaceous. Lists of the fossils identified are given by Dr. Ravn, who shows also their position in the Upper Cretaceous series from Turonian to Danien inclusive. Thus the underground geology of Denmark, a land whose surface is mostly of Pleistocene and recent formations, is carried to a depth of more than half a mile.

J. B.

3. *Das Problem der Vererbung "Erworbener Eigenschaften"*; von RICHARD SEMON. Pp. viii, 203. Leipzig, 1912 (Wilhelm Engelmann).—The possibility of transmitting to future generations any of the characters acquired during the lifetime of the individual has been very generally doubted or even denied by many biologists. An increasing mass of evidence from recent experiments has tended to demonstrate the independence of the characters contained in the germ cells from bodily influences. Yet there are still those who hold that under certain circumstances it may occasionally happen that a long continued or violent stimulus may so modify the body of an organism as to be transferred to the germ cells and thus cause a similar modification in the future offspring. Semon belongs to this latter class. In this book he presents an impartial and masterful discussion of the problem, and reviews the evidence which leads him to the conviction that these so-called acquired characters may be transmitted.

W. R. C.

4. *Principles of Economic Zoölogy. Part I, Field and Laboratory Guide*; by L. S. DAUGHERTY and M. C. DAUGHERTY. Pp. vi, 276. Philadelphia, 1912 (W. B. Saunders Company).—This is essentially a book of direction sheets for the field and laboratory study of selected types of animals. It is designed to accompany the author's text-book, *Principles of Economic Zoölogy, Part II*. The work of the student consists mainly in answering series of questions so worded as to lead him to discover for himself the important facts and principles of the subject. Alternate pages are left blank for recording the answers.

W. R. C.

5. *The Modern Warship*; by EDWARD L. ATTWOOD. Pp. vii, 146; 3 tables, 16 figures. Cambridge (University Press), and New York (G. P. Putnam's Sons), 1913.—Whether regarded as a means of preserving peace or an engine of war, the warship of modern times is a subject of great interest to many people, and those not especially informed in regard to it will find in this little book an excellent summary of the whole matter. It takes up the question of design, the various materials and steps involved in construction, and finally the point of most serious moment to the tax-payers, namely, the cost of this expensive luxury.

WARD'S NATURAL SCIENCE ESTABLISHMENT

A Supply-House for Scientific Material.

Founded 1862.

Incorporated 1890.

DEPARTMENTS:

Geology, including Phenomenal and Physiographic.

Mineralogy, including also Rocks, Meteorites, etc.

Palaeontology. *Archaeology* and *Ethnology*.

Invertebrates, including Biology, Conchology, etc.

Zoology, including Osteology and Taxidermy.

Human Anatomy, including Craniology, Odontology, etc.

Models, Plaster Casts and Wall-Charts in all departments.

Circulars in any department free on request; address

Ward's Natural Science Establishment,

76-104 College Ave., Rochester, New York, U. S. A.

Atlas der Krystallformen

von Victor Goldschmidt

This work will embrace from 25,000 to 28,000 figures of the crystal forms of mineral species, as given by the original authors. Five or six volumes of about 250 plates each are planned with a like number of volumes of text. Price for each volume: Atlas, 20 marks; Text, 12 marks; 5 marks additional for a permanent binding.

Volume I, Adamin to Buntkupferez, is now ready:
Atlas, plates 1-244; Text, pp. vi, 248.

Carl Winters Universitätsbuchhandlung, Heidelberg.

CONTENTS.

	Page
ART. XXIII.—Geologic Sketch of Titicaca Island and Adjoining Areas ; by H. E. GREGORY. (With Plate I)	187
XXIV.—Experiments on Columnar Ionization ; by E. M. WELLISCH and J. W. WOODROW	214
XXV.—Geology of the New Fossiliferous Horizon and the Underlying Rocks, in Littleton, N. H. ; by F. H. LAHEE	231
XXVI.—Liassic Flora of the Mixteca Alta of Mexico,—Its Composition, Age and Source ; by G. R. WIELAND.....	251
XXVII.—Age of the Eurypterids of Kokomo, Indiana ; by E. M. KINDLE.....	282
XXVIII.—Two Vanadiferous Ægirites from Libby, Montana ; by E. S. LARSEN and W. F. HUNT.....	289
XXIX.—Method of Increasing and Controlling the Period in Vertical Motion Seismographs ; by F. A. PERRET...	297
XXX.—Action of Sodium Paratungstate in Fusion on Salts of the Halogen Acids and Oxy-halogen Acids ; by S. B. KUZIRIAN	301
XXXI.—Use of the Sodium Paratungstate and the Blowpipe Flame in the Determination of the Acid Radicals of Chlorides, Chlorates, Perchlorates, Bromides, Bromates and Fluorides ; by S. B. KUZIRIAN	305

SCIENTIFIC INTELLIGENCE.

Miscellaneous Scientific Intelligence.—Atlas der Krystallformen, V. GOLDSCHMIDT: Dybdeboring i Grøndals eng ved København 1894-1907 og dens videnskabelige Resultater, E. P. BONNESEN, O. B. BÖGGILD og J. P. RAVN, 313.—Das Problem der Vererbung "Erworbener Eigenschaften", R. SEMON: Principles of Economic Zoölogy ; Part I, Field and Laboratory Guide, L. S. DAUGHERTY and M. C. DAUGHERTY: The Modern Worship, E. L. ATWOOD, 314.

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE,
W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS,
LOUIS V. PIRSSON, HERBERT E. GREGORY
AND HORACE S. UHLER, OF NEW HAVEN,

PROFESSOR HENRY S. WILLIAMS, OF ITHACA,
PROFESSOR JOSEPH S. AMES, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

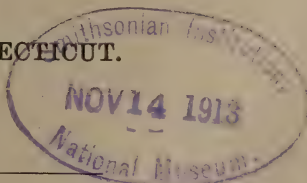
FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

No. 214—OCTOBER, 1913.

NEW HAVEN, CONNECTICUT.

1913.



THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. \$6.40 to countries in the Postal Union; \$6.25 to Canada. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).

NEW DISCOVERIES AND NEW FINDS.

BEAVERITE, A NEW MINERAL.

This mineral, which was fully described in the December, 1911, number of this Journal, I have been fortunate enough to secure the whole output of. It was found at the Horn Silver Mine in Utah and is a hydrous sulphate of copper, lead and ferric iron. It was found at a depth of 1600 feet. In appearance it resembles Carnotite. Prices 75¢ to \$2.00.

PSEUDOMORPHS OF LIMONITE AFTER MARCASITE.

These remarkable Pseudomorphs, which have never before been found in such clear cut specimens, was described and illustrated in the last number of this Journal. I have secured the majority of the finest of these specimens. They vary in size from 2 inches to 6 inches. In color they run from brown to glossy black and they have met with favor from all who have seen them. Prices from \$1.00 to \$10.00.

CHIASTOLITES.

Of these remarkable specimens, which are generally known as lucky stones, I have secured the finest lot ever found at Madera Co., California. They are cut and polished and sold singly and in collections from 25¢ to 50¢ for single specimens; 9 specimens all marked differently for \$5.00, and 18 specimens, all different markings, for \$18.00. Matrix specimens, polished on one side showing many crystals, from \$2.00 to \$8.00.

SYNTHETIC GEMS.

It is remarkable the interest that has been taken by scientists in these wonderful scientific discoveries. The Corundums are now produced in Pigeon blood, Blue, Yellow, Pink and White. Also the new Indestructible Pearls in strings with gold clasps. These are identical in hardness and rival in color and lustre the real gems. They can be dropped and stepped on without injury and are not affected by acids. My collection of the above is unrivalled, and prices of the same are remarkably low.

OTHER INTERESTING DISCOVERIES AND NEW FINDS

Will be found in our new Catalogues. These consist of a Mineral Catalogue of 28 pages; a Catalogue of California Minerals with fine Colored Plates; a Gem Catalogue of 12 pages, with illustrations, and other pamphlets and lists. These will be sent free of charge on application.

Do not delay in sending for these catalogues, which will enable you to secure minerals, gems, etc., at prices about one-half what they can be secured for elsewhere.

ALBERT H. PETEREIT

261 West 71st St., New York City.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XXXII.—*The Distribution of the Active Deposit of Radium in an Electric Field (II)*; by E. M. WELLISCH, Assistant Professor of Physics at Yale University.

Introductory.

1. THE experiments described in the present paper are a continuation of the investigation made by Wellisch and Bronson* on the distribution of the active deposit of radium in an electric field. In that investigation radium emanation mixed with air was introduced into a cylindrical condenser and the relative amounts of active deposit which settled on the central electrode and on the case were determined after equilibrium had been established for different positive potentials applied to the outer electrode.

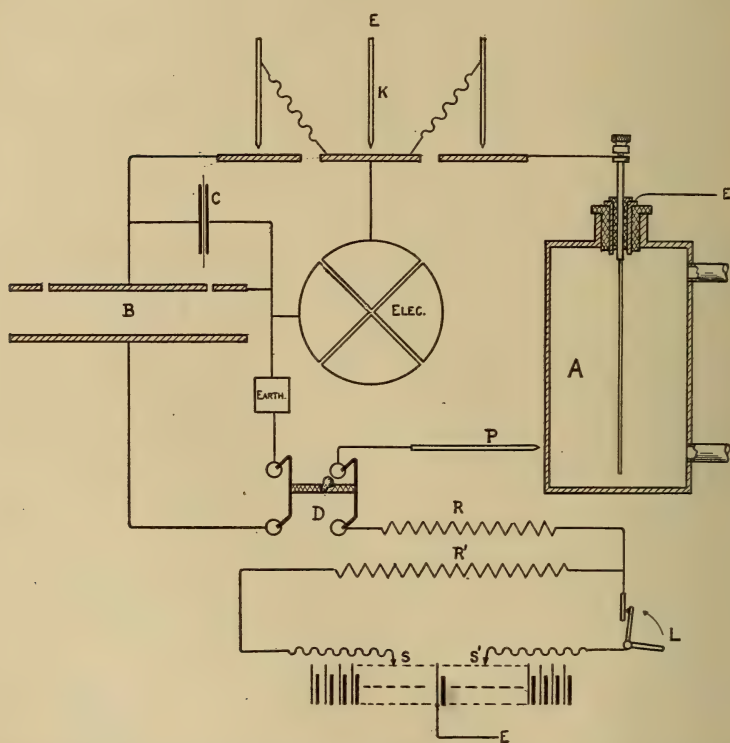
It was shown that the part of the active deposit which settled on the case (anode) was due to the diffusion of uncharged carriers; no evidence was found of the presence of negative carriers in any appreciable amount. It was found also that, when the applied potential was not too small, the distribution of the active deposit was independent of the quantity of emanation employed, and that the fraction of the total amount which settled on the cathode in general increased with increasing potentials, although under the most favorable conditions there was still about 10 per cent which was deposited on the case. The passage of Röntgen rays through the gas during the exposure was found to be without effect on the distribution except when the applied potential was small, in which case the extra ionization produced by the rays caused increased recombination with the charged active deposit particles and in this manner the cathode deposit was diminished. Finally it was found that for potentials which were not too small the ratio of the equi-

* Wellisch and Bronson, *Phil. Mag.*, ser. 6, xxiii, p. 714, 1912.

librium ionization currents in the gas for two different potentials was equal to the ratio of the corresponding cathode activities.

The main object of the present series of experiments was to extend the investigation in various directions; in particular, it was thought desirable to ascertain the effect on the distribution of employing a containing vessel of different dimensions and of mixing the emanation with gases other than air, and, in addition, to make a detailed investigation of the distribution

FIG. 1.



when small potentials were employed. The main experimental results of the previous research have been confirmed, but the fresh results which have been obtained necessitate a modification of the theory which was suggested in explanation of the phenomena.

Experimental Procedure.

2. The method employed for ascertaining the distribution of the active deposit was the same as that which had previously been employed. The radium emanation obtained usually from

a quantity of carnotite, or in some cases from an aqueous solution of a radium salt, was passed into the containing vessel and remained there under the desired conditions of potential, pressure, etc., until radio-active equilibrium was established; in general this period was about 3 hours. The emanation was blown out by means of a strong current of air from a force-pump, and the ebonite plug containing the central electrode was then removed. A fresh electrode was suspended in the vessel and the ionization current due to the 'case' activity was measured at 10 and 15 minutes after the emanation had been removed; the activity on the central electrode was measured by suspending it in a vessel of construction identical with that which contained the emanation and observing the ionization current at 20 and 25 minutes after the emanation had been removed. The activity when in equilibrium with the emanation was then calculated in the usual manner.

The diagram of connections is the same as that given in the previous paper and is reproduced in fig. 1; in the present investigation R and R' were wire resistances of 50,000 and 100,000 ohms respectively. The Dolezalek electrometer had a platinum suspension, and with 120 volts on the needle the sensitiveness was 180^{mm} per volt. C and B represent capacities which could be added to the system by means of the key K, and the total capacity of the system was then increased 21 times. A potentiometer device, not shown in the diagram, was employed when measurements of the ionization current were made; this device enabled the range of swing of the electrometer needle to be so adjusted that its mid-point coincided with the zero of the instrument, a precaution which was especially necessary, when the applied potential was small. Reference should be made to the previous paper for a more detailed account of the apparatus and method of procedure.

Experiments with a Cylindrical Condenser of small diameter.

3. In the previous experiments the greatest amount of active deposit that settled on the cathode was about 90 per cent of the total; this occurred for a potential of 4000 volts. It was of interest to ascertain the effect of applying a large potential across a smaller distance so as to obtain very large values for the electric field. For this purpose two cylindrical vessels were constructed of the following dimensions:

Height	140 mm
Inner diameter	19
Length of central electrode	101

Radium emanation mixed with air at 1 atmosphere pressure was introduced into one of these vessels, and when a positive potential of 3000 volts was applied to the case it was found

that about 86 per cent of the deposit settled on the cathode. In all probability some part of the cathode activity made its way to the ebonite insulation, but there did not appear to be any gain in the cathode deposit as a result of decreasing the cross-section of the containing vessel.

Cathode Deposit in dry Air at different pressures.

4. Throughout the remainder of the experimental investigation use was made of the two cylindrical vessels which had been employed in the previous research. These vessels were identical in construction and the dimensions of each were as follows:

Height (inside)	140 ^{mm}
Inner diameter	58
Exposed length of central electrode ...	132
Diameter of central electrode	1.83

The inner electrodes were made longer than those which had previously been employed, and care was taken that no appreciable part of the active deposit was able to settle on the ebonite insulation. During the course of the present experiments a fact was noted which had previously escaped observation. Discrepancies, in general small, occurred in the values for the cathode deposit when the experimental conditions appeared to be identical. Repeated attempts to ascertain the cause of the discrepancies were for a long time unsuccessful, but finally it was ascertained that the inconsistent results arose from the presence of small quantities of water vapor in the gas. In the previous research a test had purposely been made to find the effect of neglecting to dry the gas with which the emanation was mixed; this test appeared to show that the cathode deposit was unaffected by omitting this precaution. However, the fallacy of this result was shown by more thorough investigations. The effect of water vapor is to diminish the cathode deposit and is especially marked when the gas pressure is high and the applied potential fairly small; in these circumstances an amount of water vapor which was not sufficient to produce any perceptible increase in the recombination of the ions present in the gas might easily diminish the cathode deposit by 30 to 50 per cent. Further illustrations of this effect are given later, but in future experiments extreme care was taken to dry the gas with which the emanation was mixed. This was done by passing the gas through several tubes containing P_2O_5 and glass wool before it entered the testing vessel.

The following table gives the values obtained for the cathode deposit expressed as a percentage of the total deposit when the emanation was mixed with dried air at pressures of 210^{mm} and 760^{mm} and various positive potentials were applied to the case:

Potential in Volts	Percentage Cathode Activity	
	Air at 210 mm.	Air at 760 mm.
20	----	65.3
40	88.7	74.8
160	88.8	83.9
1030	89.2	89.2
2000	88.8	----
4000	----	89.2

These values have been corrected for the amount of uncharged deposit that diffuses to the cathode during the exposure; this correction was made by assuming that the uncharged deposit particles were distributed on the cathode and the case in proportion to the exposed areas, which were as 1:50. The figures given represent accordingly the number of positive carriers of activity expressed as a percentage of the total number of carriers.

In order to demonstrate experimentally that the activity which appeared on the anode was almost entirely due to the diffusion of uncharged carriers, several experimental determinations were made of the distribution of the active deposit when a large negative potential was applied to the case. As an example of the results obtained in this connection it was found that when the emanation was mixed with dry air at 1 atmosphere and with a negative potential of 160 volts, less than 2 per cent of the total deposit appeared on the central electrode (anode), showing that no appreciable part of the active carriers are negatively charged.

For potentials greater than about 40 volts the percentage cathode activity is independent of the amount of emanation employed unless the amount be inordinately large; over the same range of potentials, moreover, it was verified that the ratio of the two ionization currents obtained for any two potentials was identical with the ratio of the corresponding percentage cathode activities. The values obtained for the percentage cathode activity for air at 210^{mm} pressure are greater than those obtained in the previous research; it is probable that this discrepancy was due to the fact that in the previous experiment some of the ebonite insulation was exposed to the emanation so that the central electrode did not receive all the positive carriers. The insulation would probably act as a partial conductor, especially at the lower pressures when it would be exposed to the α -radiation proceeding from a considerable distance. In the present experiment this source of error was carefully avoided, and the result appears to be that the same

maximum value is obtained for the percentage cathode activity both for the lower and the higher pressure.

In the previous work the assumption was made that 100 per cent was the limiting value which the cathode deposit approached as the potential was increased, and that even at the low pressures the saturation attained was merely apparent. This assumption was made chiefly as a result of the experimental observation that the percentage cathode activity was greater at the higher than the lower pressures. Since, however, it has now been shown that the percentage cathode activity has the same value (89.2) at the higher potentials for both pressures, it appears much better to regard this as the true limiting value. The gradual increase of the values for one atmosphere for potentials above 40 volts shows that the phenomenon of columnar recombination is present; the active deposit particle recoils into the gas after the expulsion of the α -particle from the atom of emanation and tends to recombine with the negative ions which it forms along its path.

Experiments made with a steel instead of a brass central electrode gave the same limiting value for the percentage cathode activity, indicating that this value does not depend upon the nature of the material of which the electrodes are composed.

At low pressures, as is well known, a considerable number of the active deposit particles may reach the walls of the containing vessel before their velocity is sufficiently reduced to enable them to be directed by the electric field. With air at a pressure of 6^{mm} and with 180 volts the percentage cathode activity was found to be 66.7.

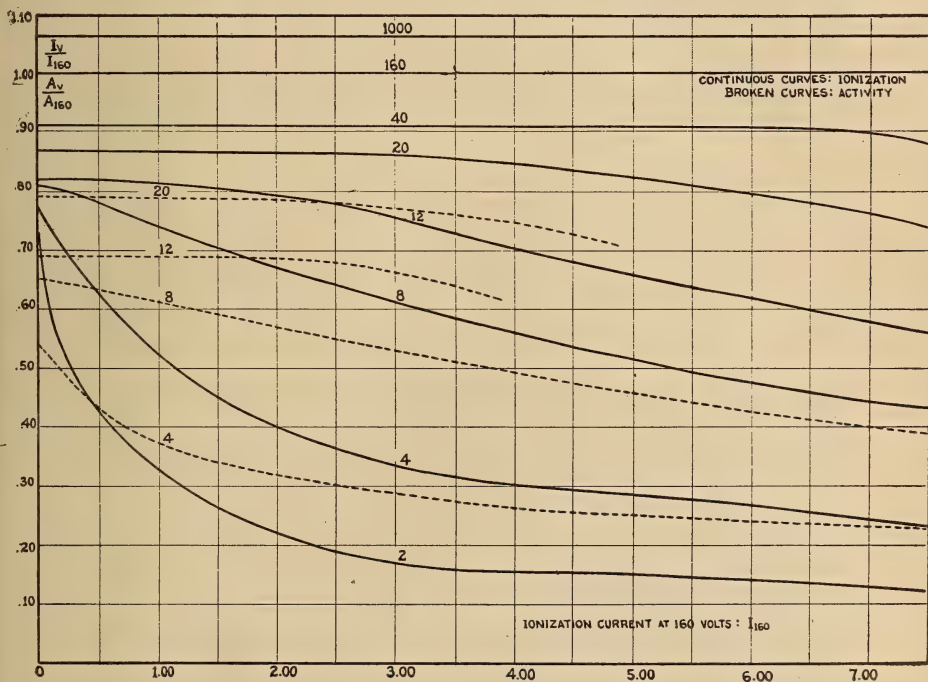
Experiments with small applied Potentials.

5. The experiments described in the preceding section refer to potentials for which the distribution of the active deposit was independent of the amount of emanation employed. For smaller potentials the distribution depends considerably on the amount of emanation; this arises from the fact that with these potentials recombination can occur between the positive particles and negative ions which are produced in the volume of the gas, whereas for the larger potentials recombination can only occur to any appreciable extent with negative ions which are present in the same column as the active particle.

A number of experiments were performed to ascertain in what manner the cathode deposit depended upon the amount of emanation for any applied potential, and especially to see whether the distribution would vary in the same way as the ionization current which passed through the gas during the exposure.

In fig. 2 there are given two sets of curves, which represent the results obtained in this series of experiments. The abscissæ represent the ionization current in scale divisions per sec (with added capacity) due to the emanation and active deposit in equilibrium when a positive potential of 160 volts was applied to the case. Inasmuch as this potential afforded the same percentage (viz. 94.3) of the saturation current whatever amount of emanation was employed, the abscissæ (denoted by I_{160}) serve as a measure of the saturation current.

FIG. 2.



The continuous curves in fig. 2 have as ordinates I_v/I_{160} , i. e., the value of the current obtained with V volts applied to the case expressed as a fraction of the current obtained when 160 volts were applied.

The broken curves refer to the active deposit and have as ordinates A_v/A_{160} , i. e., the cathode deposit obtained with V volts applied to the case expressed as a fraction of the cathode deposit obtained when a positive potential of 160 volts was applied. As mentioned above, the cathode deposit obtained for a potential of 160 volts was only 83.9 per cent of the total amount, and the maximum amount obtainable on the cathode for very large potentials was 89.2 per cent of the total.

By plotting the curves in this manner the two sets become comparable; the continuous curves afford a measure of the fraction of the total number of positive ions which reach the cathode corresponding to any potential V , while the broken curves similarly afford a measure of the fraction of the total number of positively charged particles which settle on the cathode.

A very large number of experimental results were used in order to plot the curves; for the sake of simplification the individual results are not recorded in the diagram.

The curves in fig. 2 all refer to the values obtained when the air with which the emanation was mixed was thoroughly dried as described in Section 4. The effect of a small amount of water vapor was especially marked when the applied potential was small. In illustration of this point some of the results obtained for dried and undried air are recorded below:

Air at 1 atmosphere :
 $V = 8$ volts
 dried with special caution
 containing slight traces
 of water vapor

A_v	I_v/I_{160}	I_{160}
38.4	.61	3.21
31.2	.61	3.21

It is worthy of notice that the presence of small quantities of water vapor does not appreciably diminish the fraction of positive ions which reach the cathode, whereas the effect on the number of positively charged deposit particles is considerable. It has for some time been known that water vapor is effective in causing increased recombination of ions, but the above results serve to show that the ions are not nearly so sensitive to the presence of vapor as the active deposit particles.

Referring again to the curves of fig. 2, it is seen that in general the 'activity' curve for any given voltage lies below the ionization curve for the corresponding voltage. This is almost certainly to be ascribed to the increased recombination with negative ions which occurs with the active particles as compared with the positive ions even when the air with which the emanation is mixed is thoroughly dried.

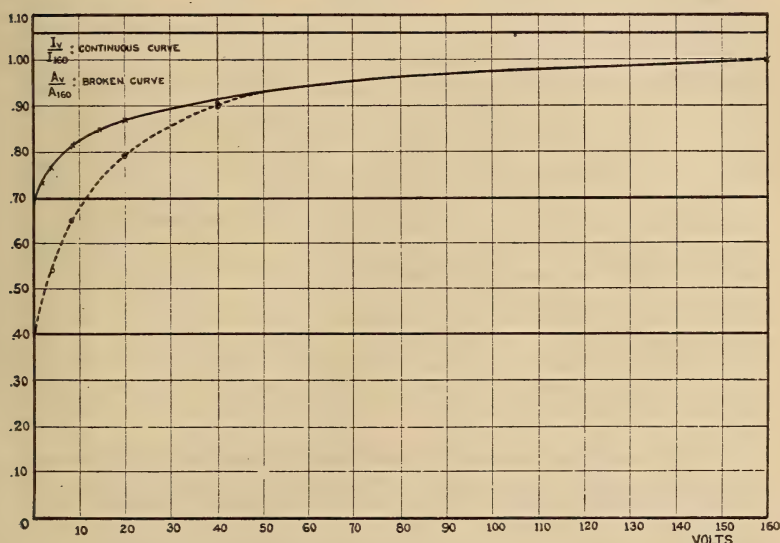
*Cathode Deposit for very small quantities of emanation
 in dry Air.*

6. If the curves in fig. 2 are produced so as to intersect the axis of ordinates, we obtain points which afford a measure of the fraction of ions and of positively charged deposit particles which would be obtained by the application of the corresponding

potential when the air in the ionization vessel contains only a very small amount of emanation. These points are plotted both for ionization current and activity as separate curves in fig. 3; they may be regarded as limiting curves which correspond to the absence of volume recombination in the vessel even at the smallest potentials employed. The upward slope of the curves is due entirely to the fact that increasing potentials prevent more and more the recombination of the positive ions or particles with negative ions which are produced inside the α -particle column.

It will be seen from the curves that any given potential brings over to the cathode a larger fraction of ions than of pos-

FIG. 3.



itively charged deposit particles; at a potential of about 40 volts the two curves practically coincide. The difference between the two curves can be explained by supposing that the negative ions which are produced in the column recombine with the positively charged active particles with greater facility than with the positive ions.

*Emanation mixed with Carbon Dioxide, Hydrogen,
and Ethyl Ether.*

7. When the emanation was mixed with dry CO_2 at various pressures it was found that the maximum value obtained for the percentage cathode activity was 80.7. In order to obtain this value with potentials less than 1000 volts the pressure had to be less than about 150^{mm}.

When the emanation was mixed with dry hydrogen the maximum value obtained for the percentage cathode activity was 89.2, the same as that obtained with air. This value could readily be obtained with a potential of 160 volts and with hydrogen at a pressure of 1 atmosphere, showing that there is very little columnar recombination in this gas. Hydrogen was found to be particularly sensitive to the presence of small traces of water vapor; the effect of the water vapor was to increase the potential necessary to obtain the same limiting value.

Inasmuch as the presence of minute quantities of water vapor resulted in a marked diminution of the amount of active deposit which settled on the cathode, it became of interest to ascertain the percentage of positively charged carriers which would result from mixing the emanation with a vapor. For this purpose ethyl ether was chosen; any gas which remained in the vessel was swept out by a stream of ether which had previously passed through P_2O_5 . The following results were obtained:

Pressure	Potential	Percentage Cathode Activity
mm	Volts	
82	160	6.4
85	1070	9.8
128	do	10.0
235	do	10.8

At the highest pressure there was a large current passing through the vapor during the activation due mainly to the fact that the ether being near the point of condensation was partly conducting; this conduction current may have been responsible for the increased amount of the cathode deposit at the highest pressure. Apart from this it appears that for ether vapor the limiting value of the cathode activity is approximately 10 per cent.

Summary and discussion of results.

8. When the emanation is mixed with any gas there appears to be a definite limit to the fraction of the active deposit which settles on the cathode. This limit is independent of the pressure of the gas, provided it is high enough to prevent the deposit particles from recoiling on to the walls of the vessel; it is in general dependent on the nature of the gas. This limiting value is in general obtained only with large potentials; with smaller potentials the fraction of the cathode deposit is

decreased as a result of columnar recombination of the positively charged particles with negative ions; and with very small potentials the charged particles recombine with negative ions in the volume of the gas. Small traces of water vapor have a considerable effect in diminishing the number of positively charged particles; the water vapor appears to be effective in bringing about increased recombination, both volume and columnar, between the charged particles and the negative ions.

It has been shown in Section 5 that even in air which has been thoroughly dried the recombination between the charged deposit particles and the negative ions is greater than the recombination between the positive and negative ions. This result, which is in all probability to be ascribed to the larger size and mass of the deposit particles, is not in accord with the experimental result of H. W. Schmidt,* who came to the conclusion that as far as recombination and mobility are concerned the active particles behave as positive ions.

The process which accompanies the deposit of the active particles on the cathode appears to be most suitably explained in the following manner. At the moment of expulsion of the α -particle from the atom of emanation the residual part recoils into the gas; in air at a pressure of 1 atmosphere the range of this recoil atom has been shown to be about $\frac{1}{10}$ mm. As it moves through the gas the recoil atom produces a large number of ions and in the act of ionization it is possible that the recoil atom may lose its positive charge. On the other hand recoil atoms which at any time are uncharged may regain a positive charge, so that if we consider a large number of recoil atoms there will at any given moment be a certain fraction which carry a positive charge, the remainder being practically all neutral. The process is in many respects similar to that which is known to occur in the case of canal rays. During the motion of recoil the atom is practically unaffected by any applied electric field, so that initially the relative number of uncharged and charged recoil atoms is independent of the applied potential. However, when the recoil atom has reached the end of its path, if it be positively charged it may lose its charge by recombination with a negative ion formed in the column; this recombination can be prevented by increasing sufficiently the applied potential. Moreover for small applied potentials a positively charged recoil atom may recombine with a negative ion in the volume of the gas.

When both columnar and volume recombination are avoided by the application of a sufficiently high potential the distribution of the active deposit on the electrodes is determined

* H. W. Schmidt, *Phys. Zeitschr.*, ix, p. 184, 1908.

entirely by the relative number of charged and uncharged carriers resulting from the recoil of the atoms of Ra.A in the gas. Under these circumstances we should expect that the distribution should be independent of the pressure of the gas because the recoil atom will meet the same number of gas molecules before it is brought to relative rest. Of course if the pressure is too low an appreciable number of active deposit particles will recoil on to the walls of the vessel and in this manner the cathode deposit will be diminished.

Although nothing has been established in this research with regard to the velocity of the recoil atoms when moving under the influence of an electric field, nevertheless there is distinct evidence that, as far as diffusion and recombination are concerned, the recoil atoms behave differently from the positive gas ions. It has been shown in Section 5 that, when recombination occurs between negative ions on the one hand and positive ions or positive recoil atoms on the other hand, a considerably smaller fraction of recoil atoms than of positive ions is received by the negative electrode. This is especially the case with moist gases, but even in gases which had been dried with the utmost care the difference is well marked. An examination of the curves of fig. 3 seems to afford further information in this connection. The curves may be regarded as giving the fraction either of positive ions or of positively charged recoil atoms that is received at the negative electrode for any given potential, volume recombination being supposed to be entirely absent. It will be noticed that these curves cut the axis of ordinates at the points marked .7 and .4, these points representing respectively 66 per cent of the total number of positive ions and 38 per cent of the total number of positively charged deposit particles. This type of curve has already been treated by Wellisch and Woodrow* for the case of the columnar recombination resulting from α -particle ionization. It was shown by them that the ordinate of the point of intersection represents the fraction of the total number of ions which escapes from the α -particle column as a result of molecular agitation and diffusion. Inasmuch as volume recombination is absent these ions are brought over to the electrodes by a very small electric field. If we draw through the point of intersection a straight line parallel to the axis of potential and if we refer the curve to this straight line as a new axis of potential, then the new ordinates will indicate to what extent the electric potential is effective in preventing recombination between those ions which still remain in the column after the initial diffusion has occurred. If we treat the curves of fig. 3 in a similar manner we see that, whereas in the vessel employed

* Wellisch and Woodrow, this Journal, September, 1913.

66 per cent of the positive ions on the average escaped from the α -particle column, the corresponding figure for the positively charged recoil atoms was only 38 per cent. This slowness with which the recoil atoms diffuse is readily ascribable to their relatively large size and mass. Of those ions and recoil atoms which do not escape by diffusion from the column approximately the same fraction is brought over by any given potential; it seems that there is here some compensating influence at work; probably the greater tendency of the recoil atoms to recombine with negative ions is partly balanced by the smaller number of encounters with these ions.

The existence of a definite limiting value to the percentage cathode activity has been ascribed above to a continual process of gain and loss of charge which occurs during the recoil motion of the active deposit particle. It is to be expected that this limiting value will depend upon the nature of the gas into which the particle recoils; the experimental determination showed that this was in general the case although the limiting value for hydrogen was within the limits of error the same as that for air. The fact that the value for ether is as small as 10 per cent is surprising and is in all probability to be ascribed to the ease with which the molecules of ether are ionized.

ART. XXXIII.—*Adjustment of the Quartz Spectrograph;*
by C. C. HUTCHINS.

THE most common form of quartz spectrograph is constructed with a single Cornu prism with simple collimating and camera lenses of right and left rotation, and is the form to which the following remarks apply. It is an extremely useful type of instrument for recording the complete spectrum easily accessible to photography, and in the ultra-violet has a resolving power only exceeded by a large grating. It would doubtless find more extended use were it not for the very tedious operation of putting it into perfect adjustment, complete directions for which do not seem to be easily accessible. Eder,* who had the advice and assistance of Schumann in the construction of his apparatus, after giving incomplete directions for adjustment dismisses the matter with the remark that: "Die Ermittlung der zweckdienlichsten gegenseitigen Stellung von Collimator, Prisma und Platte ist eine zeitraubende Arbeit."

One well-known European maker furnishes an instrument ready adjusted for use. The writer has examined and used two of these, both large and expensive instruments, and has found their performance far from satisfactory. The makers have in fact not made use of easily available information in their design. Owners of such instruments will be glad to know that they are capable of great improvement, while those having the type in which all adjustments must be made by the user, will, it is hoped, have their task considerably lightened by the following directions.

Lens focus.—It is important that the lenses should not be of too short focus. For a prism of medium size—say 4^{cm} high by 5^{cm} on the face, plano-convex lenses of 70^{cm} focus for yellow sodium light are correct, and for the following reasons:

1. If the optical parts are good that focal length of camera lens is needed in order to realize upon the photographic plate the full resolving power of the prism.

2. With the best adjustment possible the spectrum does not lie in a plane but along a diacaustic curve to which the plate must conform, and with a camera lens of 70^{cm} focus the resulting curvature is about as great as the ordinary commercial plate will bear without danger of breaking,—in fact it is safer to sort out any very thick plates and to use them for other purposes.

The plate holder.—As is well known, the plate makes an angle of about 25° with the axis of the camera lens, and should

* Beiträge zur Spectralanalyse.

be slightly adjustable about that position. Any projecting portions of the plate-holder, at the ends of short waves, that might prevent the oblique rays from reaching the very end of the plate, should be cut away; for, with a focus of 70^{cm} the spectrum just occupies the length of a 10-inch plate.

The plate should be firmly held by buttons or otherwise and bent over ways along its edges to a curve whose radius is four times the focal length of the camera lens for sodium light.

Focus of the collimator.—The distance of the slit to the collimator lens should be 87 per cent of the focus of the collimator lens for sodium light.

Adjustment of the prism.—The collimator and camera lenses should come close up to the prism. Lay off on a sheet of zinc an angle of 55°3, cut out and file the edges true. Lay one edge of this templet across the front of collimator and rotate the prism until its face fits the other edge of the templet. This adjustment causes light of wave-length about 2025 to pass at minimum deviation, and is a much more ready means of setting the prism than is finding the minimum deviation by successive exposures and rotations of the prism, while at the same time it is sufficiently accurate for all purposes. The angle of the prism is supposed to be 60°; should it be otherwise it is merely required to calculate, in any case, the deviation for λ 2025 and cut the templet accordingly.

Adjustment of the camera.—The spark spectrum of copper is excellent for adjusting purposes. The lines are not remarkably sharp but are numerous and well distributed throughout the spectrum from the red to λ 1979. Using a high-tension transformer (Woods' Cail), large condenser, Seed No. 26 plate, two seconds was found to give a well exposed negative from λ 5000 to λ 2150.

A valuable addition to the apparatus is a shutter hinged on the inside of the camera, and movable by a handle from without. When swung parallel to the plate it covers all but the extreme ultra-violet end of the spectrum and enables giving a long exposure to the shortest waves without over-exposing the remainder. To get the line 1979 from one-half to one minute is required.

The camera is supposed to be furnished with some sort of focussing scale, and further, a scale for measuring the plate inclination.

An unexposed but fixed plate being placed in the plate-holder it may be focussed at the visible end of the spectrum, which should lie at the extreme end of the plate. The best focus being found, draw out the camera 3 or 4 millimeters.

Now with a plate in the camera make an exposure near the edge of the plate, move the camera in one millimeter at a time

and advance the plate each time, so as to secure a succession of images.

From an inspection of the resulting negative the point of sharpest focus at the middle of the plate may be found. On a plate 2 inches wide 6 or 8 exposures may be made. The negative obtained as above will probably also show which way the plate must be inclined in order to bring the ends into focus, which is accomplished by successive small changes of inclination and exposure as outlined above. When the proper inclination is found, it is best to go back and change the focus by fractions of a millimeter at a time in order to secure the finest definition possible. The operator is advised to use short exposures, as over-exposed lines often present the same appearance as lines out of focus.

An improvement in the definition in the region of long waves may often be effected by partial screening of the prism by placing stops over the lenses. With a prism 4^{cm} high and 5^{cm} on the face the writer uses stops of 3.5^{cm} opening. This opening being greater than the curtate face of the prism, there is no loss of resolving power, and the loss of light is, in all ordinary cases, immaterial.

With a good optical equipment the above proceeding should result in excellent definition from end to end of the plate, the lines showing sharp under magnification and free from wings.

Bowdoin College, Brunswick, Me., July 17.

ART. XXXIV.—*The Stability Relations of the Silica Minerals*; by CLARENCE N. FENNER.

Introduction.

Determination of the inversion points between quartz and tridymite and between tridymite and cristobalite.

The appearance of unstable phases.

Suggested explanation of anomalous results previously obtained.

Natural occurrences of tridymite and cristobalite.

Effect of pressure upon the quartz-tridymite inversion.

Information to be obtained from the study of tridymite-bearing rocks.

Physical properties of artificial quartz, tridymite, and cristobalite.

Preparation of quartz in aqueous solution.

General observations on the quartz-tridymite-cristobalite inversions.

Low temperature inversions.

Relations of chalcedony to other forms of silica.

Fusion of cristobalite and quartz.

Summary.

INTRODUCTION.

MUCH work has been done at various times on the relations between the different forms of silica which are found as natural minerals, and the literature of the subject is extensive. A portion of what has been written has been based upon laboratory experiments, a portion upon observation of natural occurrences, and still a third portion upon theoretical considerations. Each method of attack, when properly applied, is a legitimate means of attempting to arrive at a solution of a problem, and in the paper which follows, each will be resorted to to a certain degree, but chief stress will be laid upon the results attained by experimental investigation.

In spite of the work done upon the problem, the results previously attained can hardly be considered to be satisfactory. The conclusions reached from the experimental side were not concordant; those derived from observation of natural occurrences indicated the relations in a general way, but were not sufficiently explicit and also contained contradictions which no theoretical consideration was able to clear up. For these reasons, the Geophysical Laboratory took up the problem several years ago, and the work done at that time resulted in considerable advance in our knowledge of the relations of the several forms. In the first publication in which the matter was discussed,* the inversion point between quartz and tridymite was placed at approximately 800° and the melting point of tridymite (or, more properly, the change from the crystalline to the amorphous condition) was considered to be about 1600° . At

* The Lime-Silica Series of Minerals, A. L. Day, E. S. Shepherd and F. E. Wright, this Journal, (4), xxii, 265-302, 1906.

that time the relations were supposed to be much more simple than was found shortly afterward to be the case. This was due principally to the fact that the mineral cristobalite was almost unknown at the time, and only the relations between the two forms, quartz and tridymite, were considered. In reality, the products classed as tridymite consisted at times of tridymite and at other times of cristobalite. The optical properties of the two are so similar that the fact that two different products were obtained was not realized, although it was noted that the index of refraction in some preparations was slightly higher than normal. It may be noted also that the values of refringence and birefringence of cristobalite given in some of the standard mineralogies are in error. By consulting Mallard's* original paper, from which they are quoted, it is obvious that the value of the index has been misprinted and that of the birefringence probably misinterpreted.

In a second paper from the Geophysical Laboratory,† dealing with the matter, attention was called to the inaccuracy in some of the statements of the preceding paper, and it was stated: "Recent work on the silica problem, at low temperatures, has shown it to be much more complicated than was at first supposed. In fact, several phases have now been found to occur in that region which were not disclosed by the first investigation. The problem as a whole is not simple, and has not yet been satisfactorily solved, so that in the following paragraphs only a report of progress can be made."

Through the courtesy of Professor Lacroix of Paris, to whom specimens of the artificial crystals obtained by the devitrification of silica glass and by heating quartz at high temperatures, had been sent, it had been shown that these were probably cristobalite and not tridymite as had formerly been supposed. The acceptance of this view, however, seemed to open up again the whole question, for if this mineral was cristobalite, what was the position of tridymite in the series? In fact, beyond the determination that tridymite and cristobalite were high temperature forms, nothing seemed certain regarding their relations. This uncertainty was increased by the fact that other investigators had reported the artificial production of tridymite and cristobalite under such conditions that it seemed even a question whether they were properly high temperature minerals. The manner of their occurrence in nature also suggested the possibility that their field of stability was in the region below 800°. On the other hand, Professor Koenigs-

* E. Mallard, *Bull. Soc. Min.*, xiii, 175, 1890.

† The Binary Systems of Alumina with Silica, Lime and Magnesia, E. S. Shepherd, G. A. Rankin and F. E. Wright, *this Journal*, (4), xxviii, 293-333, 1909.

berger,* in consideration of the evidence which he believed to exist for the precipitation of quartz from magmas at temperatures as high as 1000° , had expressed the opinion that the transformation quartz-tridymite might perhaps be monotropic.

The low temperature inversion of α into β quartz, of α - β tridymite, and of α - β cristobalite, was described in the later paper from this Laboratory, to which reference has been made. The velocity with which these reactions occur, compared with the reluctance with which quartz inverts into tridymite or cristobalite, had been noted as a very striking phenomenon, for which no explanation could be suggested. Further investigation of these reactions seemed desirable.

These problems were held in abeyance by the Laboratory for some time in the stress of other work. At the first opportunity, however, they were again taken up in the hope that with the advantage of the knowledge gained from previous investigations, the problem might be cleared up. The specific points which were obscure and for which a solution was desired, were the following:

1. Are the relations between the forms chalcedony, quartz, tridymite, and cristobalite monotropic or enantiotropic?

2. If enantiotropic, what are the fields of stability of each, and what are the inversion points?

3. What is the explanation of the observed fact that both in natural occurrences and in the results of experimental work, quartz, tridymite, and cristobalite appear to have been formed at times almost simultaneously, or at least under conditions under which not all could be stable?

4. What is the reason for the remarkable velocity of the α - β inversions of quartz, tridymite, and cristobalite as compared with the slowness of transformation of each of these minerals into one of the others?

5. To which form of silica does the previously determined melting point belong?

To these may be added a sixth question which arose in the course of the work and, from its theoretical importance, demanded solution.

6. Is the temperature of inversion of α into β cristobalite a fixed point and is its apparent variability due to some such recognized factor as impurity of material or lag, or is it actually a movable point and therefore an extraordinary type of phenomenon?

To some of these questions the present investigation has supplied categorical answers. To others the direction in which experimental work points for the explanation brings one upon debatable ground and caution must be used lest positive con-

* J. Koenigsberger, Neues Jahrb., Beilageband, xxxii, 113, 1911.

clusions be arrived at without supplementary evidence. The explanations suggested for these debatable problems must be looked upon merely as contributions toward a final solution of the theoretical questions involved.

After the investigation had been under way for some time a preliminary paper was published.* In this a brief outline was given of the chief results obtained up to that time. In the present paper it has seemed desirable to present the results as a consistent whole, so far as possible, and in order to do this all results of importance will be given and their relations discussed without much regard to the previous publication.

DETERMINATION OF THE INVERSION POINTS BETWEEN QUARTZ AND TRIDYMITITE AND BETWEEN TRIDYMITITE AND CRISTOBALITE.

As previous work had demonstrated that the above inversions take place very slowly, and that the minerals may be heated at high temperatures and for long periods with no indication of inversion or with only partial inversion as the result, it was realized at the outset that it was necessary to employ a flux or catalytic agent of some sort to hasten the process. This should be such a material as would melt at a comparatively low temperature and would not be volatilized to a serious degree at high temperatures. It should, moreover, not dissolve silica in large quantity or enter into solid solution with any of the silica minerals. A number of reagents were tried at various times, such as potassium and lithium chlorides, boric acid, and salt of phosphorus, but the one which best fulfilled the requirements was found to be crystallized sodium tungstate ($\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O}$). This possessed the added advantage that it could be removed by simple washing with water. The only difficulty found was that at high temperatures (1400° and over) it dissolves a considerable quantity of silica, and if much is used nothing but a glass results. This difficulty was easily overcome by using a small quantity.

For reactions at a high temperature, that is, in the neighborhood of the tridymite-cristobalite inversion-point, sodium-potassium silicate may likewise be employed. It offers no special advantages over sodic tungstate, except that it may be regarded as more similar in its nature to a magmatic melt.

In establishing the inversion points, the method of procedure was simple in principle but rather tedious in its application because of the slowness with which equilibrium is established. A charge was first prepared by melting sodic tungstate in a small platinum crucible over a Bunsen flame and adding the respective form of silica and mixing with a platinum stirrer. The crucible, to which a short wire had been fused on each

* The Various Forms of Silica and their Mutual Relations, C. N. Fenner, J. Wash. Acad. Sci., ii, 471-480, 1912.

end of a diameter so as to form a sort of bucket, was then suspended from corresponding wires hanging from the lower end of a Marquardt porcelain tube. A thermoelement, of the standard material used in the Geophysical Laboratory (pure platinum against 90 Pt 10 Rh), was run down through the Marquardt tube and into the charge. The thermojunction within the charge was bare, while the upper portions of the wires were insulated from each other by inclosing them within capillary porcelain tubes. The upper ends of the thermoelement wires were attached to corresponding terminals of the ice-bath, from which copper wires led to the potentiometer in the usual manner. Electromotive force was read from a mirror galvanometer in connection with the potentiometer, in the usual form adopted by the Geophysical Laboratory, whose details have been fully described in previous papers* and need not be gone into. Full precautions against leakage of electric current into the galvanometer circuit were employed. A check was maintained on the accuracy of the readings of the thermoelements by occasional calibration by comparison with the melting points of standard substances ($\text{MgCa}(\text{SiO}_3)_2 = 1391.2^\circ$, $\text{Li}_2\text{SiO}_3 = 1200^\circ$, gold = 1062.4° , $\text{Na}_2\text{SO}_4 = 884^\circ$, zinc = 419.4°).

By means of the device described, the bucket containing the charge could be inserted into a furnace heated by an electric current passing through a platinum resistance coil, and subjected to whatever heat treatment was desirable.

If one heats ground quartz in sodic tungstate at 1000° or more for several hours, it is found to have been more or less completely converted into tridymite. On the other hand, if tridymite so prepared is mixed with tungstate and heated at 800° for a long period, innumerable small quartz crystals can be perceived in the resultant product. Somewhere between these two temperatures, therefore, there must lie an inversion-point. At high temperatures the transformation of quartz into tridymite can easily be carried to completion. The reversion of tridymite into quartz can likewise be completely carried out but is more sluggish, and generally no attempt was made to convert the whole charge because of the length of time which would be required. The quantity of quartz increases with the period of heating, but having once established the reversibility of the process, nothing would be gained by continuing it for excessive periods. It simply remained to determine a temperature above which tridymite could be recognized as having been obtained from quartz and below which quartz as obtained from tridymite. It was found that within a few degrees of the

* A. L. Day, E. T. Allen, and J. P. Iddings, Publication No. 31, Carnegie Inst. of Washington; A. L. Day, E. S. Shepherd, and F. E. Wright, in this Journal, (4), xxii, 265-302, 1906; W. P. White, in Phys. Rev., xxv, 334-352, 1907; and in this Journal, (4), xxviii, 459-489, 1909.

inversion-point the velocity of transformation was extremely small and a long period of heating was required to insure the appearance of the stable phase, but outside of this range a noticeably less time was required. Fine grinding apparently did not increase the velocity of the reaction.

As the range within which the inversion lay was gradually narrowed down great care was exercised in the regulation of furnace temperature. The method of procedure was to hold the charge for a long period at some temperature previously decided upon, keeping close watch to see that some unexpected variation in the strength of the heating current did not cause a departure from this temperature. When necessary to continue heating from one day to the next (as was frequently the case) the current from the generator was replaced by that from storage batteries. These batteries possessed very constant voltage and were of such capacity that in a run of fifteen or sixteen hours the temperature of the furnace dropped only 8–10 degrees.

A description of several of the more significant experiments follows:

No. 82. A mixture of finely ground silica glass with sodic tungstate; length of heating, 11 hours 20 minutes, during which the temperature was kept very close to 865° , extreme variations 863° – 875° . The product was essentially tridymite, but distinct quartz grains were found, often with bipyramidal terminations. (As will appear a little later, the tridymite was an intermediate stage, and the point of significance is the fact that it was changing to quartz at this temperature.)

No. 102. A mixture of artificial tridymite and sodic tungstate; length of heating, $73\frac{1}{2}$ hours; utmost variation, 854° – 864° ; general temperature, 858° . The product was still mostly tridymite, but there were very numerous quartz crystals, mostly as nuclei of tridymite aggregates.

No. 103. Ground quartz with sodic tungstate; length of heating, 24 hours; general temperature, 875° ; range, 865° – 877° ; product, quartz with considerable tridymite in hexagonal plates.

Other experiments of the same nature might be described, confirming the above results and fixing the temperature of inversion at a point very close to 870° .

Because of the great difficulty of keeping the temperature of the furnace constant for such a length of time, some latitude must be permitted in expressing the temperature of inversion, but it is believed to lie within 10° of 870° .

It has not been considered necessary to tabulate the results of experiments conducted much above or below 870° , for at such temperatures quartz changed to tridymite in the one case and tridymite to quartz in the other in an unequivocal manner.

In determining the inversion-point between tridymite and cristobalite the same general method of procedure was followed, but the details were slightly different. As before, temperatures were first found above which tridymite changed to cristobalite and below which cristobalite changed to tridymite, and the range was gradually brought within narrow limits. For final determination, however, it was not considered advisable to depend upon the constancy of the storage batteries over night, because of the draught which would be imposed upon them by the heavy heating-current. Therefore the charge under treatment was withdrawn at night and quickly cooled, and replaced in the morning at the same temperature and heating continued. No difference in principle was involved in thus breaking up the time of heating into several periods.

The final experiments were as follows:

No. 114. Mixture of cristobalite and sodic tungstate; length of heating, $4\frac{3}{4}$ hours at $1460^{\circ} \pm 2^{\circ}$; the product is still mostly cristobalite, but there is a very appreciable quantity of tridymite.

No. 117. Mixture of tridymite and sodic tungstate; length of heating, 10 hours 25 minutes at $1475^{\circ} \pm 2^{\circ}$; product is mostly tridymite, but with considerable cristobalite.

No. 122. Tridymite and sodic tungstate; $21\frac{1}{4}$ hours at $1470^{\circ} \pm 2^{\circ}$; no cristobalite discoverable.

No. 120. Cristobalite and sodic tungstate; 16 hours at $1470^{\circ} \pm 2^{\circ}$; no tridymite discoverable.

From these experiments, in connection with many others at higher and lower temperatures, which gave consistent results, we appear to be perfectly justified in placing the tridymite-cristobalite inversion temperature at $1470^{\circ} \pm 10^{\circ}$.

The enantiotropic relations were confirmed by numerous experiments, modified in various ways. Starting with quartz either tridymite or cristobalite may be obtained, according to the temperature used. Likewise, tridymite may be converted into quartz or into cristobalite, and cristobalite into quartz or tridymite. Silica glass and amorphous precipitated silica have likewise been converted at will into any one of the three crystalline modifications. In all its relations to other forms precipitated silica behaves in the same way as silica glass, and may probably be considered as the same chemical substance, differing only in its state of physical division.

There can be no doubt that quartz, tridymite, and cristobalite are enantiotropic forms, each with a certain range of stability. Their general equilibrium relations are shown in fig. 1, in which the coördinates are temperature and vapor-pressure. The absolute values of vapor-pressure are, of course, unknown, but we may make use of the principle that the vapor-pressure rises with temperature, and that the vapor-pressure of a stable

form is less than that of an unstable form. An inversion-point lies at the intersection of two vapor-pressure curves. These same relations apply to the functions free energy and thermo-

FIG. 1.

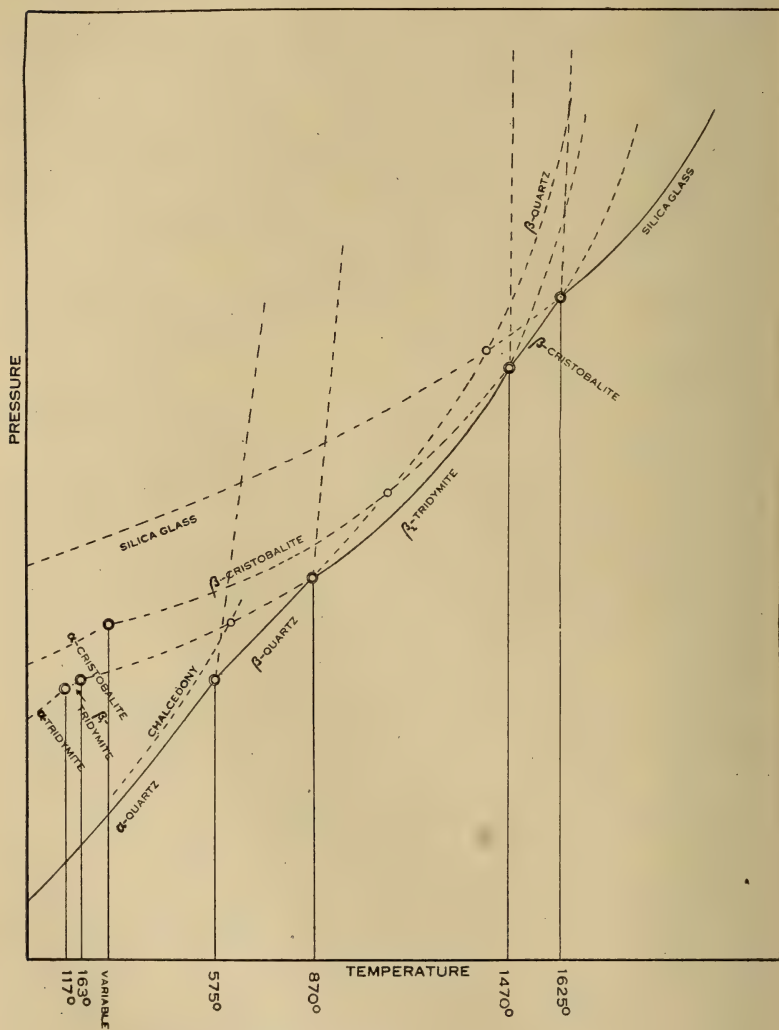


FIG. 1. Stability relations of the silica minerals.

dynamic potential, and, as absolute values are unknown, the vapor-pressure coordinate could as well be considered as a coordinate of free energy or thermodynamic potential.

THE APPEARANCE OF UNSTABLE PHASES.

In experiments on the relations of the various forms, certain phenomena were met which were rather puzzling at first, but after their explanation was perceived it was recognized that they threw considerable light upon discrepancies shown in the results obtained in previous work upon the silica minerals, and upon the conditions under which tridymite and cristobalite have been formed in nature. It was found, for example, that if silica glass or precipitated silica was heated with sodic tungstate for a number of hours at 800–850°, not quartz but tridymite was first obtained. It was only after much longer heating that quartz crystals began to appear, although this is the stable form at that temperature. It seems that in the passage from the amorphous condition to quartz, the whole is first converted into the intermediate form tridymite, and only secondarily into quartz.

Likewise, if either amorphous modification is heated without a flux at 1300° or 1400°, cristobalite alone is obtained, although the temperature is within the range of tridymite. The process halts at the cristobalite stage, and can only be carried to completion by the addition of a flux. Similarly, ground quartz heated without a flux at high temperatures but still below the 1470° inversion-point is changed to cristobalite and not tridymite, which might be expected.

A striking instance of the formation of unstable phases appeared in a series of experiments in which one or another form of silica was heated with a large excess of sodic tungstate over a Bunsen burner. In one instance in which amorphous precipitated silica was thus heated for 43 hours, quartz, tridymite, and cristobalite, all in good crystals, were found in the same melt. In other instances, quartz or tridymite or cristobalite was similarly employed and two or three of the phases were simultaneously obtained. The crystalline outlines were such as to indicate new formation of even that phase which was added at the beginning. Working in this manner one may start with tridymite and, keeping the temperature in all parts of the crucible within the tridymite range, convert part of the tridymite into cristobalite—a result which at first sight seems impossible.

The production of unstable phases in this manner has considerable theoretical importance. In its proper interpretation light may be thrown upon some apparent discrepancies in former work and make possible a reasonable explanation of natural occurrences of tridymite and cristobalite. It also seems to have some bearing upon recent theories of the structure of molecules and crystals. It will, therefore, be discussed at some length and an endeavor made to interpret its significance.

From the standpoint of the kinetic theory, the question of the formation and appearance of a mineral phase may be looked upon as a function of two variables; first, the *probability* of the requisite number of moving particles coming together in the pattern appropriate to the structure of the mineral in question, and second, the *strength of the bonds* by which the particles thus assembled are held together under the impact of other particles or under the stress of intramolecular forces. Both of these are again functions of the temperature and pressure, but vary with these according to very different laws.

Under this conception, when a number of substances enter into a reaction, or when a single substance is subjected to a change of conditions under which it is no longer stable, a certain assemblage of particles characterized by a simple* pattern may be formed at a given temperature and pressure in great numbers, while a second assemblage characterized by a more complex pattern is formed in the same interval in much less quantity; and the relative velocity of formation and destruction of the two may be such that the phase appropriate to the first pattern will appear as a new phase of the system, while the second is present in only infinitesimal quantity; but we may easily suppose that each group of the second phase, when once formed, is relatively indestructible under the given conditions, while the groups of the first kind are continually breaking down and reforming. The result will be that the phase which appeared with such rapidity at first will gradually yield place to the second phase, which will then be the *stable* phase. The second phase may, however, under some conditions, be formed with such slowness (on account of the small number of free particles which escape from the phase already formed or because of the complexity of its pattern) that it will not appear in recognizable quantity, and the unstable phase will persist indefinitely.

By changing the temperature and pressure, we change the two variables according to different laws, and the results obtained as regards the phases which first appear and as regards the phases which are stable, vary accordingly. At transition points the opposing tendencies are in equilibrium, or in other

* Simple and complex, as here used, refer to probability or improbability of the particles coming together in the manner to form the pattern in question.

R. J. Strutt (Proc. Roy. Soc. London, ser. A, lxxxvii, 302-9) has made some interesting calculations on this sort of molecular statistics. He concludes that probably a single collision with a silver surface is sufficient to destroy a molecule of O_3 , but that a molecule of active N must collide 500 times with an oxidized Cu surface before it is destroyed, and that two molecules of O_3 at 100° must collide 6×10^{11} times before the right sort of collision occurs for the formation from them of 3 molecules of O_2 . (Chem. Abstracts, vii, 6, 923, 1913.)

words, the formation and destruction of each of two phases proceed at the same rate. Below the inversion-point the formation of one of the phases exceeds its destruction; above it the other phase is thus characterized.

Let us apply this conception to the specific case of the simultaneous formation of crystals of quartz, tridymite, and cristobalite in a sodic tungstate melt. In this experiment there is some evidence that a reversible reaction of this kind proceeds:



going from left to right at higher temperatures and from right to left at lower. In this manner a multitude of SiO_2 molecules are constantly contributed to the liquid, in which they are in active movement. By chance collisions numbers of these meet in such manner as to form groups of definite patterns, which tend to cohere. According to their arrangement, they form the quartz, tridymite, or cristobalite molecules, each of which appears and disappears in countless numbers at each instant. Under the conditions of the experiment, a stream of ungrouped molecules is constantly added to the cooler portions of the melt by the breaking-up of Na_2SiO_3 (or by convection currents from below), yielding such an overwhelming excess over what would occur under more uniform conditions of temperature that all possible configurations of grouping (which seems to mean those appropriate to quartz, tridymite, and cristobalite) are formed, and the number of each kind formed is in great excess over those destroyed. Each sort of crystal is, therefore, deposited from the melt. If none of the crystals settled into the hotter regions below, we should ultimately find that after the exhaustion of the supply of ungrouped molecules, two of the kinds of crystals would pass into the third, as for this the excess of production over destruction would be greater than for either of the other two, and this would be the stable form at this temperature; but under the influence of convection currents, the process continues around and around in a circle indefinitely.

In the process thus presented, I have conceived that by regular arrangements of the simple SiO_2 molecule more complex groups corresponding to quartz, tridymite, and cristobalite *molecules* are first formed in the liquid, and that these again group themselves in appropriate patterns to form the respective *crystals*. The question may arise whether such primary groupings occur apart from the crystal groupings. There is abundant evidence, however, from various sources, that simple molecules do form groups of this nature in a liquid, so-called associated molecules. Moreover, evidence will be presented later that cristobalite crystals at least give phenomena which are best

explained by the assumption of two different kinds of molecules in the same crystals. It seems most probable, therefore, in consideration of all the phenomena, that different molecular groupings of SiO_2 take place in the melt under the circumstances described, and that when crystallization ensues, these complex molecules arrange themselves in the appropriate patterns corresponding to the respective crystals. The minerals are regarded, therefore, as being not only polymorphic but polymeric.

The reactions of silica which have been mentioned appear to follow very closely the requirements of the principle which Ostwald enunciated and which is known as Ostwald's rule, or the law of successive reactions. As formulated by him, it is as follows:* "In all reactions the most stable state is not straightway reached, but the next less stable or that state which is the least stable of the possible states." The reasoning by which he endeavors to show the necessity of reactions taking this course is based upon a consideration of the diminution of free energy of a system. It seems to imply that because the free energy in passing from a stage A to a lower stage C passes through the level B, the phase corresponding to this level must always appear, but there is no necessity that this should hold. The matter resolves itself into the question whether under *unstable* conditions the quantity of free energy in a system defines its state. Expressed in this form, we can answer definitely that it does not, any more than the somewhat parallel functions of vapor-pressure or thermodynamic potential.

Applying a kinetic conception, if we can imagine a sodic tungstate melt saturated with simple ungrouped silica molecules at 850° , and then allow such reactions as tend toward equilibrium to take place for a minute space of time, while it is probable that cristobalite groups, because of the relative simplicity of structure usually accompanying high temperature forms, will have been produced in greater numbers than tridymite groups, yet at the end of a longer interval it is doubtful if this would be the case. The strength of the union holding together the members of each cristobalite group would probably be so slight at this temperature that after the rapid attainment of a certain maximum number, equivalent numbers would be destroyed as rapidly as others formed, while the number of tridymite groups would continually increase until the solvent was saturated and crystals were deposited. In the latter sequence of events, the level of free energy represented by B would be that pertaining to a mixture composed mostly

* W. Ostwald, *Principles of Inorganic Chemistry*; translation by A. Findlay, 1904, p. 211.

of tridymite and unassociated silica instead of that pertaining to cristobalite.

Thus it seems that whether we regard Ostwald's principle from a thermodynamic standpoint, applying the principle of minimum free energy, or whether we use a kinetic conception of the process as a guide, its validity as a general law is questionable.

Although the reactions of silica show a number of phenomena to which Ostwald's principle is applicable, exceptions are also found. Thus if a mixture of amorphous silica and sodic tungstate is heated to 800–850°, in a few hours only tridymite can be found. By much longer heating quartz crystals appear. At no stage can cristobalite, the intermediate form between amorphous silica and tridymite, be detected. Likewise, silica glass or precipitated silica, heated without a flux at any temperature at which devitrification occurs, always gives cristobalite, but just above 1470° it should first give tridymite if Ostwald's rule applied. Quartz heated without a flux for a very long period at 1300° gives cristobalite, in obedience to Ostwald's principle. Heated with a flux for three hours at the same temperature, it gives tridymite with no indication of an intermediate cristobalite phase.

SUGGESTED EXPLANATION OF ANOMALOUS RESULTS PREVIOUSLY OBTAINED.

From the results obtained by former investigators of the silica diagram, it had been pretty well established that the quartz-tridymite inversion-point lay between 800° and 900°. The exact temperature was rendered uncertain from the fact that in a number of cases amorphous silica was employed as the initial material, which, as we have seen, in the presence of a flux yields tridymite at temperatures considerably below the true inversion-point. The significance of this has been discussed, and it has been shown that with longer heating the tridymite obtained would have gone over into the stable form quartz. Similarly misleading phenomena appeared in the endeavor to determine the position of cristobalite in the series. By heating either quartz or amorphous silica without a flux, cristobalite will be obtained at temperatures much below its field of stability.

These discordant phenomena may all be interpreted as instances in which Ostwald's principle applies, and their appearance need give rise to no uncertainty.

NATURAL OCCURRENCES OF TRIDYMITE AND CRISTOBALITE.

The mode of occurrence of natural tridymite and cristobalite implies that in many cases they have been formed as

unstable phases. Cristobalite especially could seldom if ever have been deposited as a stable mineral in the circumstances in which it is now found. Its usual occurrence is in cavities in eruptive rocks, which would certainly have been in a fluid condition at temperatures within the range of stability of this mineral. The appearance of the inclosing rocks in many cases, however, suggests that the formation of the cristobalite is to be ascribed to its deposition from mutually reacting vapors or to the decomposition of former silicate minerals or siliceous glass by pneumatolytic processes. In either of such modes of action, unassociated molecules of silica would be set free in quantity from their previous state of combination with other elements, and would probably tend to form groups among themselves corresponding to cristobalite. This is perfectly analogous in principle to the formation of cristobalite in tungstate melts over a Bunsen flame at a comparatively low temperature, which was obtained as a result of direct experiment and for which the explanation has been suggested. It is quite certain that for the deposition of the mineral in question under such conditions no excessively high temperature is demanded and its presence in no wise implies that the temperature requirements of stability obtained.

Many of the occurrences of tridymite are similar and likewise suggest the intervention of gases in its production, as has been pointed out in a number of instances by A. Lacroix.* An interesting association of tridymite and quartz in hollow spherulites of rhyolite is described by Iddings and Penfield,† and appears to be due to processes of this character. The presence of trapezohedral faces on the quartz crystals shows that it is of the *a* variety, and therefore formed below 575°.

In addition to such occurrences, which point to pneumatolytic action, tridymite is sometimes found as an essential constituent of acid effusives, associated in such manner with other minerals as to imply its separation from the melt as a primary constituent. In such instances the implication is simply that at some period in the previous history of the magma the temperature was such that the excess of silica not required to form other minerals had formed the molecular groupings corresponding to tridymite, and when rapid cooling ensued these groups crystallized out in the tridymite form. The temperature at the time of crystallization may have been either above or below the 870° inversion-point. If below, the viscosity of the melt acted as an effective obstacle to prevent that rearrangement of the molecules which would be demanded to form quartz. With less rapid cooling and especially with

* A. Lacroix, *Bull. Soc. Min.*, xxviii, 56, 1905.

† Iddings and Penfield, *this Journal*, (3), xlii, 39, 1891.

decrease of viscosity by the retention of volatile substances (mineralizers)—conditions implying a crystallization of the magma under pressure—tridymite if once formed would become unstable at 870° and would pass over into quartz. This matter will be taken up a little later.

Through the kindness of Dr. E. S. Larsen, of the U. S. Geological Survey, my attention has been called to an interesting occurrence of cristobalite in a basalt found by Dr. Whitman Cross in the Hawaiian Islands. In the calculation of the norm from the chemical analysis of the rock, no olivine appeared, while examination of thin sections showed abundant olivine. The explanation was found in the discovery of small crystals of cristobalite in cavities. In another set of rocks from Colorado which Dr. Larsen brought to my attention, the flow-structure of acid effusives is well developed and certain of the bands show innumerable tridymite crystals whose arrangement with respect to the other constituents of the rocks indicates their simultaneous crystallization from the melt. It seems probable that these minerals are not so rare as has been generally supposed and that with careful search they might often be found.

Emphasis should be laid upon the fact that the presence of cristobalite or tridymite in a rock does not necessarily imply that at the time of formation of these minerals the temperature was above the respective inversion-points (1470° and 870°). Any set of conditions which will bring together quantities of ungrouped SiO_2 molecules in such a manner as to favor their rapid assemblage in definite groupings without giving time for perfect equilibrium to be established (as in the reactions of vapors); or which will suddenly bring a system in which equilibrium prevails into new conditions, at the same time introducing obstacles to the establishment of a new equilibrium (as in the sudden chilling of a melt), will favor the deposition of unstable forms. It is evident that there will be two factors to be considered; first, the question of whether change of conditions has been too rapid for equilibrium to follow, and second, the question as to what was the previous condition from which the state in question has been reached.

Certain phenomena which Lacroix and others* have described, where quartzose inclusions in volcanic rocks have been partly or wholly transformed to tridymite or to tridymite and cristobalite, seem to show that here the 870° inversion-point has been exceeded. Some uncertainty on this point arises from the observation which Lacroix makes† that, in the

* A. Lacroix, *Les Enclaves des Roches Volcaniques*, 1893; *Bull. Soc. Min.*, xiv, 185, 1891; K. v. Chrustschoff, *Tschermak Min. Pet. Mitth.*, vii, 295, 1886.

† *Les Enclaves des Roches Volcaniques*, p. 570.

cases which he has observed, such newly formed tridymite seems always to be due in some way to the intervention of mineralizers, and, as previously shown, the reactions of vapors are likely to produce tridymite at a temperature below its range of stability. Nevertheless the most probable explanation for the phenomena which Lacroix describes seems to be that the temperature was sufficiently high to break up the quartz molecule and give opportunity for the formation of new groupings corresponding to tridymite and cristobalite.

A reproduction of the essential conditions attending the engulfment of quartzose material by a liquid magma was attempted in one experiment. Potassium carbonate, sodium bicarbonate, and ground basalt were mixed in approximately equal proportions, and eight or nine times as much ground quartz was added. The whole was heated in a Fletcher furnace to a high temperature (1500–1600°) and melted to a clear, slightly greenish glass, in which small spherulites had formed on cooling. This glass was then placed in the electric furnace and devitrified by holding at 1000° to 1400° for five hours. It was then found to be filled with a mass of tridymite crystals. A portion of this was mixed with a large excess of quartz and the whole well ground. Heated again for 22 hours at 1200–1400°, the final result was a mixture of tridymite and cristobalite, although the temperature appropriate to the cristobalite region had never been reached. The results are similar in kind to those observed in the basaltic rocks of Mayen,* where quartz inclusions have been partly converted into cristobalite and tridymite, and is to be ascribed to the breaking-up of the quartz molecules by the high temperature attained, giving opportunity for new arrangements to form, without facilitating rearrangement to such a degree that all the groups reached stability.

The question arises, whether in the cooling of a magma quartz may appear outside of its range of stability, as several authors have supposed. The possibility of this is not wholly excluded, but nothing has been found in the experimental work which suggests anything of the kind, and on theoretical grounds it appears inherently improbable. The equilibrium from which the magma has cooled is one corresponding to the presence of tridymite molecules in the solution. It is difficult to conceive the formation and precipitation of quartz from such a solution *above* the inversion-point, while the precipitation of tridymite *below* this point is perfectly intelligible when the cooling is rapid. The effect of pressure in shifting the inversion-point itself is not here considered, but will be taken up later.

* A. Lacroix, Bull. Soc. Min., xiv, 185, 1891. P. Gaubert, *idem*, xxvii, 42, 1904.

A question of considerable importance is, whether the general absence of tridymite in rocks which have cooled slowly (such as large bodies of deep-seated intrusives) must be understood as proving that the temperature of crystallization was below the tridymite-quartz inversion-point. Considered solely from the experimental evidence on the quartz-tridymite relations, it may probably be said that the temperature during the *final* stages of crystallization of the quartz was below this point, but nothing is implied regarding the *first* stages; for if tridymite were precipitated at an earlier stage, but remained in contact with a fluid portion of the magma after the temperature dropped below the inversion-point, it would probably pass over into quartz within a short time (probably within a few days). Examples are not lacking in which traces of such inversion appear to survive. The peculiar form of quartz in some eruptives has been thus explained. Professor Lacroix* has found a number of instances of such relations, and Dr. Per Geijer† has recently described others.

In the examples just referred to, the peculiar form of the quartz bears testimony to the history through which it has passed, but under different conditions, especially those obtaining during the crystallization of a coarsely granular rock, the newly formed quartz would undoubtedly tend to assume its proper crystallographic structure, and no evidence of the intermediate steps of the process could be found in the final product.

It is hardly necessary to consider in detail the various natural occurrences of tridymite and cristobalite which have been described in the literature. So far as I have been able to ascertain, the descriptions given bear out the principles of origin which have been outlined.

EFFECT OF PRESSURE UPON THE QUARTZ-TRIDYMITE INVERSION.

In the preliminary paper on the silica minerals which the writer published, some inquiry was made into the effect which pressure would have in displacing the inversion point. By employing the Clausius-Clapeyron equation $\left(\frac{dT}{dp} = \frac{T}{L}(v_2 - v_1)\right)$ and assuming probable values of L , the heat of inversion, and $v_2 - v_1$, the volume change, a displacement (rise) of 0.10537° per atmosphere was deduced. It is doubtful, however, if a calculation of this kind serves any useful purpose because of the lack of certainty of the values assumed and the consequent

* A. Lacroix: Sur la tridymite du Vésuve et sur la genèse de ce minéral par fusion, Bull. Soc. Min., xxxi, 323, 1908.

† Per Geijer: Geol. Fören. Förhandl., xxxiv, 1, pp. 51-80, 1913. References are given in this paper to instances cited by other writers.

unreliability of the results and the danger that they will be misinterpreted. The data for such a calculation would be of great value, but until they are available, we can hardly make a more positive statement than to say that pressure will raise the inversion-point by some unknown amount.

INFORMATION TO BE OBTAINED FROM THE STUDY OF TRIDYMITE-BEARING ROCKS.

A careful study of the relations and characteristics of the minerals in tridymite-bearing rocks should give us important information on certain problems connected with the processes of volcanic activity. The position of the quartz-tridymite inversion-point is within a critical region as regards the temperatures of vulcanism, and the history of the tridymite, as revealed by petrologic study, may, with the accumulation of evidence, be able to settle a number of debated points. The kind of evidence to which I refer may be illustrated by an example. In the set of rocks from Colorado which Dr. Larsen kindly placed at my disposal, I have found certain very suggestive features, which appear to show that quartz phenocrysts which were formed in the magma at depth, became converted into tridymite during the process of extrusion. The nature of the evidence is as follows: When in laboratory experiments ground quartz is converted into tridymite in a sodic tungstate flux, it is frequently found that many of the quartz grains retain their individuality during the process, but are replaced by an aggregate of tridymite crystals. If the replacement has not been quite complete, very irregular nuclei of quartz remain, corroded by the encroaching tridymite. Similar phenomena have been remarked in the transformation of quartz bricks into tridymite in metallurgical establishments or glass furnaces.* In the Colorado rocks certain tridymite aggregates suggest the same sort of process carried to completion. They are distinctive units, quite sharply set off from the surrounding matrix, which frequently bends around them in flow lines. They are not spherulites, as the component crystals are disposed at random instead of in a radial form, and are much larger than ordinarily found in spherulites. Perhaps most important of all is the observed fact that in several instances the outlines of the nodules are those of slightly rounded hexagons. All in all, the appearance suggests a derivation from quartz phenocrysts. The rocks in which the phenomena occur may be called tridymite-latites; that is, rocks corresponding in mineralogical make-up to quartz-latites but in which the rôle of quartz as an essential constituent is taken by tridymite.

* E. Mallard, *Bull. Soc. Min.*, xiii, 172, 1890; P. J. Holmquist, *Geol. Fören. Förhand*, xxxiii, 4, 245-260, 1911; K. Endell, *Stahl u. Eisen*, Nr. 10, 1912.

This single observation requires support from other directions. If it should be confirmed its interpretation leads to interesting deductions. The explanation which first suggests itself is that under great pressure quartz phenocrysts had formed in the magma at a temperature considerably above the 870° inversion-point, and that with relief of pressure accompanying the movement toward the surface, the position of the inversion-point was lowered to such a degree that tridymite became the stable phase and transformation followed as a natural consequence; but we are not justified in accepting this explanation at once. We cannot focus our attention upon this one phenomenon and neglect the results which would arise among the accompanying constituents, that is, upon the magma as a whole, from relief of pressure. In a mixture of such great complexity as a partly solidified magma, consisting of solids, liquids, and dissolved gases, a change of pressure will be accompanied by transformations and reactions among all the components tending toward a new condition of equilibrium. The direction of all such reactions will be governed by a single principle, that the net result shall be an increase of volume of the mass as a whole when the pressure is decreased. Necessarily such reactions will be attended by an evolution or absorption of heat, but this factor does not influence the direction of reaction except secondarily, and, moreover, there is no general parallelism between the amount of the volume change and the quantity of heat evolved or absorbed. It is certain that from such internal reactions (neglecting losses of heat by conduction or radiation to the surroundings) the temperature of the magma will either rise or fall, but observations of volcanic phenomena have not yet supplied data from which it is possible to affirm which is the general result. There is, therefore, at least the possibility that in the rise of a magma from the depths the temperature may actually become greater, perhaps even to a notable degree. If this should be the case, the transformation from quartz to tridymite might well be explained from this alone, and the fact that the direction of volume-change in this one constituent is that demanded of the magma as a whole would be a mere coincidence.

PHYSICAL PROPERTIES OF ARTIFICIAL QUARTZ, TRIDYMITE, AND CRISTOBALITE.

In determining the transition points between quartz and tridymite and between tridymite and cristobalite, it was necessary, as previously explained, to use a solvent or catalytic agent in order to cause the transformation to proceed at an appreciable rate, and sodic tungstate was selected for the purpose. The use of this material is permissible if it gives rise to no

product which enters into solution with one or another form of silica. If such solution occurred, the inversion-points would be displaced and the determinations made would have no special significance. It is necessary, therefore, to show that the artificial products do not represent solid solutions. For this purpose chemical analysis has little value. A number of analyses were made by volatilizing the silica with hydrofluoric acid and weighing the residue. This residue was always rather small (0.19–0.60 per cent.), but its effect depended wholly upon the question as to whether it was mixed with the crystalline silica as a mechanical impurity or whether it had entered into solution with it. To settle this, the determination of physical properties fortunately provides effective criteria. Certain of these properties are of such a nature that they would be even more affected by a slight amount of foreign material in solid solution than would the transition points mentioned. Therefore, by a comparison of the properties of the artificial minerals with those of their analogues in nature, the probability of identity can be established. Outside of this, the physical constants are inherently of value and their determinations should be recorded.

Properties of Quartz.—The quartz obtained in sodic tungstate melts seldom exceeds 0.1^{mm} in length. The crystals appear to be simple combinations of prism and pyramids. Frequently the forms are rounded or distorted, an effect which, with some crystals, can be seen to be due to oscillatory development of faces. Ordinarily, each crystal is a separate individual, with double terminations, and a general habit similar to quartz phenocrysts in porphyries. Determination of refractive indices was made in sodium light by matching the index of the crystals with that of various oils by the Becke line method, the index of the oil mixture which matched being immediately determined on a total refractometer. The agreement with natural quartz was very close. For artificial $\omega = 1.544$ $\epsilon = 1.551$ (temperature 23°), for natural $\omega = 1.544$ $\epsilon = 1.553$.

Strong confirmation of its identity with natural quartz was furnished by comparison with the α - β inversion point of the natural mineral (to be described later). The quantity of heat involved in this transformation is so insignificant (3–4 calories* per gramme, according to unpublished determinations by W. P. White of this Laboratory) that a small amount of material in solution would tend to produce a decided shift. The average of three determinations gave the point as 577.2° on heating and 568.5° on cooling. Within the limits of error of the method, these points coincide with those of natural quartz.

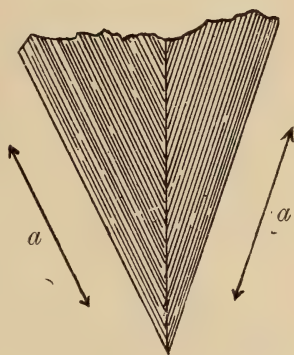
* The exact amount of heat change to be considered is variable because of an increase of specific heat just prior to the inversion, which must be taken into account when the displacement is considerable.

Properties of Tridymite.—The most frequent form of tridymite as obtained by the inversion of quartz in a tungstate melt is as aggregates of crystals of random orientation replacing each quartz grain. In addition, large numbers of perfectly formed hexagonal plates are almost always present in the same preparation. Ordinarily the crystals are quite minute, but it is not difficult to produce them at will of such size that individual crystals are plainly visible to the naked eye. The essentials seem to be a long period of heating and a moderately high temperature. After one experiment, conducted at 1300° for 23 hours, the crust of the mass in the crucible appeared somewhat fissured and the openings were lined with relatively large, separate crystals of a tabular form. Under a binocular of moderate power their hexagonal form could be distinguished. Interpenetration twinning was developed to a high degree, and although the crystals were too frail for goniometric work, the resemblance to the twins and trillings figured in Dana and Hintze was striking. In another experiment the heating was continued for 140 hours at a temperature varying from 900° to 1200° and still better crystals were obtained.

The crystals in random aggregates frequently show elongated or lath-like shapes, due to their being cross-sections of the thin scales. In such cases the extinction is parallel to the elongation, and the elongation has the vibration direction a . In other cases the wedge-like twinning frequently noted in descriptions appears. This has the appearance shown in fig. 2.

The hexagonal scales, when of the thinness ordinarily obtained, appear perfectly isotropic when lying on the base. The larger ones secured by special effort are found to be divided into slightly birefringent fields, as shown in fig. 3. The acute bisectrix in each distinct area is normal to the plate and the optical character is positive. The planes of the optic axes are related to the exterior crystal boundaries in such a way as to be always normal to an edge. The shape of the fields, though quite irregular, is also plainly related to the crystal outline. The hyperbolic brushes are broad and rather faint, and the value of the axial angle is therefore difficult of accurate determination. Three measurements gave the following results for $2V$: 32.6° , 38.0° , 35.8° , average 35.5° , or $2E = 58.6^{\circ}$. Determination of refractive indices in sodium light by the immersion method gave for vibrations parallel to plates (α and β)

FIG. 2.



1.469 (difference too small to be determined), perpendicular to plates (γ) 1.473 (temp. 24°). All these characteristics agree closely with those of the natural mineral, as given by Mallard,* whose determinations and descriptions are usually cited. Mallard found difficulties in exact determinations of optical constants, but gives $\frac{\beta + \gamma}{2} = 1.477$, $\gamma - \alpha = 0.00185$, $2E = 66^\circ$ about, and $2V = 43^\circ$ about.

A determination of specific gravity was made by the method of Day and Allen.† The value found was 2.270 for tridymite

FIG. 3.



FIG. 3. Tridymite crystal in basal position ; length about 1.0mm.

at 27° referred to water at 27° . Mallard gives 2.28 for the natural mineral.

The optical characteristics of the low temperature ($\alpha -$) form of tridymite indicate orthorhombic symmetry. Each hexagonal plate appears to be made up of several orthorhombic individuals whose vertical axes are parallel with the vertical axis of the hexagonal crystals, but which are twinned after a 60° orthorhombic prism coinciding with the 60° hexagonal

* E. Mallard, *Bull. Soc. Min.*, xiii, 161, 1890.

† Publication No. 31, Carnegie Inst. of Washington, p. 55, 1905.

prism. In the transformation from the high temperature to the low temperature form there appears to be but little shifting of the elements of the space-lattice.

The low temperature inversion of tridymite has long been known. Further investigation has made it appear that there are in reality two inversions lying less than 50° apart, of which the lower is the one ordinarily observed. The method of determining the temperature of these inversions and their meaning will be discussed later. Only a small energy change is involved in either, and therefore a small amount of material in solid solution would probably cause a noticeable shift in their positions. This fact gives to the lower inversion a value as a criterion for judging the identity of the natural and artificial minerals. Mallard* placed the inversion-point of natural tridymite at $130^{\circ} \pm 5^{\circ}$. This seems to be the only determination recorded. My own observation on natural tridymite from Cerro San Cristobal in a thermal microscope indicated a somewhat lower value, about 112° . With artificial tridymite the average of a number of closely concordant results obtained by methods in which I place greater confidence, gave 117.4° .

On the whole, the physical properties of artificial tridymite show close agreement with those of the natural mineral, and there is little reason to doubt that they are the same substance.

Properties of Cristobalite.—It is a little more difficult to prove that the cristobalite obtained from tungstate melts carries no foreign material in solid solution. A peculiar situation arises from the fact that the inversion of α into β cristobalite does not take place at a definite temperature like the corresponding inversions of quartz and tridymite, but the temperature for any given preparation depends upon the conditions under which it was formed, and that entirely apart from any question of impurity. This variability eliminates it as a criterion. Moreover, the properties of natural cristobalite are rather imperfectly known. Efforts were made by this Laboratory to obtain specimens of the mineral from dealers for purposes of comparison, but the material submitted was practically useless. Nevertheless it is possible to establish a strong presumption of the identity of the natural and artificial minerals.

The values of the index of refraction and birefringence usually cited in standard works are those of Mallard.† Mallard gives the value of the index as 1.432, which is evidently a misprint for 1.482, for he immediately states "c'est-à-dire sensiblement égal, ou peut-être un peu supérieur à celui de la tridymite." P. Gaubert‡ has called attention to the error, and has made a redetermination, which, however, he did not con-

* E. Mallard, Bull. Soc. Min., xiii, 171, 1890.

† Ibid., 175, 1890.

‡ P. Gaubert, *ibid.*, xxvii, 42, 1904.

sider entirely satisfactory. The mean index, he says, is near 1.49. For artificial crystals prepared in a tungstate melt I have determined the indices in the manner described for quartz, and obtained $\gamma = 1.487$ $\alpha = 1.484$ (sodium light, temperature 24°). Mallard determined the value of the birefringence as 0.00053. There seems to be here also an error of some kind. At any rate, the artificial crystals show a birefringence nearly equal to that of tridymite, probably a little less. M. Bauer, describing the crystals of vom Rath's* original discovery, speaks of the "ziemlich kräftige Doppelbrechung."

Determination of the specific gravity by the method of Day and Allen gave 2.333 for cristobalite at 27° referred to water at 27°. Mallard found 2.34 for natural crystals.

As ordinarily obtained, the artificial cristobalite shows considerable general resemblance to the elongated form of tridymite. The difference in indices of refraction, however, while slight, is sufficient ordinarily for discrimination. Moreover, the extinction of cristobalite in such aggregates is not parallel to any recognizable crystallographic feature, and again, cristobalite grains frequently show a distinct polysynthetic twinning like that of albite, or a plaid effect like microcline. It is a fact not without significance in considering the possibility of material being taken up in solution by cristobalite formed in tungstate melts, that cristobalite, unlike quartz and tridymite, can be formed without a flux and the material so prepared does not differ observably from that formed with a flux. Even those preparations obtained by aid of a flux show very little impurity, 0.19–0.35 per cent according to several analyses.

The best crystals of cristobalite have been obtained by heating amorphous silica with sodic tungstate over a Bunsen burner. They then show an attempt to develop a definite crystal form, but generally arrive at no better results than the forms illustrated in fig. 4. Many of the dihedral and polyhedral angles are nearly perfect, but the remainder of the crystal is a mere skeleton framework. At times the principal growth has been in the direction of one axis only, more often along two or three at right angles to each other. Crystals frequently show many more branches than those illustrated, but the general form of growth has been the same.

In every case where terminal caps have been developed they appear to be octahedra. It is not possible to get very exact measurements of such small crystals under the microscope, but, as nearly as determinable, the edges make angles of 90° with each other and the plane faces make angles of practically 70°. From the relations of the caps to the axes of elongation,

*G. vom Rath and Max Bauer, *Neues Jahrb.*, i, 200, 1887.

it seems that the direction of elongation is always that of cubic axes. In many cases the direction of growth has been influenced by twinning. This is evident at once in such a form as shown at *c* and is the natural explanation wherever the angles between axes differ from 90° . The best measurements that could be made with the microscope show that angles which do not differ sensibly from 45° and 60° occur. The mode of

FIG. 4.

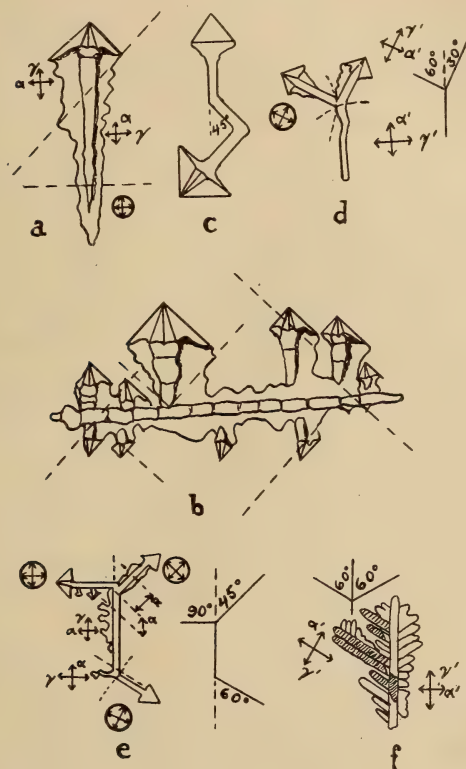


FIG. 4. Cristobalite crystals; size 0.1–0.2mm.

twinning which would give such results as regards the directions of the axes and which is in accord with the observed positions of the faces is twinning after the octahedron (111) or spinel twinning. If, after twinning has occurred at some point during the growth along an axis, the same axis continues to grow, an angle of 60° is formed. If, however, a second axis, which would normally assume a 90° position, starts growth in the twinned position, an angle of 45° results.

The general crystallographic symmetry of cristobalite indicates that under the conditions of formation it is actually an isometric mineral, but in cooling to ordinary temperatures it passes through an inversion, by which it becomes birefringent. In the sketches of cristobalite crystals shown in fig. 4, dotted lines indicate the birefringent fields and arrows show vibration directions. Crossed arrows in a circle show that no birefringence is perceptible. In the last case, the crystals should be perpendicular to an optic axis, or nearly so, but because of the weak birefringence of the mineral and the small thickness of the crystal, no indication whatever of an interference figure could be perceived in convergent light. The sections which showed maximum birefringence, however, gave a figure apparently perpendicular to an optic normal (β). From this it was possible to determine that the acute bisectrix is a and hence the mineral is negative. This agrees with Mallard's determination on natural crystals. The manner in which the birefringent fields are arranged also agrees with Mallard's observations. The plane of secondary twinning is generally quite sharp and makes an angle of 45° or 90° with the cubic axis which it crosses. In some instances, however, the border of adjacent fields is quite irregular, as in *f*. The position of the secondary twinning plane and the relations which the vibration directions bear to each other is concordant with the idea of tetragonal or orthorhombic* symmetry of the low-temperature form, with twinning after a 45° pyramid parallel to an octahedral edge of the original crystal. During inversion, therefore, the crystallographic space-lattice seems to suffer but little distortion. The tendency to assume skeleton forms agrees with the description of natural crystals, as does the occurrence of twinning after the spinel law.†

PREPARATION OF QUARTZ IN AQUEOUS SOLUTION.

Quartz may be prepared without difficulty by heating either silica glass or amorphous precipitated silica with water and sodic carbonate in a silver-lined steel bomb at 400° to 500° for two or three days. The relative proportions of materials need not be very exact; approximately the following were used in several experiments: water 8°C , silica 2–3 g., crystallized sodic carbonate 0.7 g., capacity of bomb 16°C .

Experiments of this kind have been performed a number of times and have no special interest. Of more importance was an investigation as to the possibility of obtaining tridymite or

* E. Mallard, *Bull. Soc. Min.*, xiii, 175, 1890. A. Lacroix, *ibid.*, xiv, 186, 1891.

† G. vom Rath, *Neues Jahrb.*, i, 198, 1887. P. Gaubert, *Bull. Soc. Min.*, xxvii, 242, 1904.

cristobalite under such conditions. A number of experimenters have reported the formation of these two minerals in aqueous solution and this fact had, in the beginning, given rise to uncertainty in regard to the stability relations of the three.

In all my experiments with amorphous silica in alkaline solutions, quartz was obtained. When artificial tridymite or cristobalite was substituted for amorphous silica, quartz was likewise obtained as the end-product. This removed any uncertainty that had been felt as to the relative stability of the three minerals under such conditions and confirmed the results obtained in tungstate melts.

To obtain as much information as possible on the question, it was thought desirable to repeat several of the experiments cited in the literature, in which tridymite or cristobalite was reported.

E. Baur,* in one of his experiments (No. 8) took 5 g. SiO_2 , 4.3 g. $\text{Al}_2\text{O}_3\text{Na}$ (composition between soda leucite and nephelite) and obtained quartz, tridymite, and albite. The tridymite was described by Weinschenk as follows: "tablets, made up of countless differently oriented individuals, plainly less refringent than Canada balsam, weakly birefringent, small axial angle, optically positive." To repeat this, I placed in a bomb of 16^{cc} capacity a thorough mixture of 2.5 g. amorphous precipitated silica and 2.15 g. NaAlO_2 (the latter made by heating a mixture of Na_2CO_3 and Al_2O_3 in molecular proportions to 1400°); 6^{cc} of water was added. The bomb was heated to approximately 520° for five hours, then heating current was turned off and the bomb cooled with furnace over night. The resulting product consisted apparently of two different minerals. The first was in sharp, hexagonal prisms cut off squarely by basal pinacoid, elongation negative, both indices >1.530 and <1.535 . The crystals are attacked by dilute HCl , leaving at times crystalline fragments in an amorphous material (probably gelatinous SiO_2). This conforms to nephelite except for slightly lower index. The second material was in roundish granules having at times a suggestion of crystal outline, was isotropic and had index just below 1.490; apparently analcite.

This experiment was performed three times, with some variation as to length of heating and rate of cooling. The products were always the same.

Although these results do not agree with those obtained by Baur, I do not consider that one disproves the other. There can hardly be any question that quartz is the stable mineral under these conditions, but it might well happen that from some combination of circumstances the intermediate form

* E. Baur, *Zs. phys. Chem.*, xlii, 567-576, 1902.

tridymite was first produced and from lack of time did not pass over completely into quartz.

K. v. Chrustschoff,* by heating soluble amorphous silicic acid in an aqueous solution of hydrofluoboric acid for five hours, obtained the following results: at 180–228°, regular crystals, perfectly isotropic, index = 1.58 (possibly a misprint for 1.48), contain 99.78 per cent SiO_2 ; 240–300°: quartz; 310–360°: tridymite with some quartz.

The regular crystals were considered to be cristobalite, although the index as quoted is markedly different. No data on the tridymite are given in the German abstract.

The writer placed in a bomb of 18^{cc} capacity 4 g. amorphous precipitated silica, 3^{cc} hydrofluoboric acid, made by saturating a 40 per cent solution of HF with B_2O_3 ; and 3^{cc} water. These were heated 22 hours at 350–380°. The product was mostly unchanged amorphous silica, with which there were a few small but perfectly formed crystals of quartz.

Cristobalite and especially tridymite have been reported as formed similarly in a wet way in numerous instances and natural occurrences due to a similar mode of formation have likewise been reported. There is no reason known why they should not have been deposited as *unstable* forms under such conditions, but these two minerals possess such neutral properties that great care must be exercised in identification and other possibilities must be eliminated before reaching a positive conclusion in such instances.

GENERAL OBSERVATIONS ON THE QUARTZ-TRIDYMITE-CRISTOBALITE INVERSIONS.

The experimental work which has thus far been described has been concerned principally with establishing the stability relations of the three minerals. During the course of the investigation, however, a considerable amount of data was accumulated regarding the conditions under which one form may be converted into another regardless of whether the product was the final or stable form, and regarding the reactions which may be expected under various conditions of treatment. Some of these results are important in establishing points in the unstable fields of the complete silica diagram. The whole may be summarized as follows:—

Neither quartz nor tridymite has been formed under any conditions in the absence of a solvent.

At temperatures below 870° quartz was always produced when any form of silica was heated for a sufficient length of time in a sodic tungstate melt or in aqueous solution. In a sodic tungstate melt the most favorable temperature seemed to

* K. v. Chrustschoff, Neues Jahrb., i, Referate 240, 1897.

be about 825°. Here the conversion of the whole charge takes about three days. A lower working limit to the use of sodic tungstate is imposed by its solidification at 698°. Although quartz is the stable form below 870°, either amorphous silica or cristobalite first yields tridymite and only after much longer heating does quartz appear.

Between 870° and 1470° tridymite is always formed in a tungstate melt. From 1300° upward the reaction is fairly rapid. At high temperatures (1400° and upward) an alkaline silicate glass may be used as a flux. The best crystals of tridymite have been obtained in a tungstate melt at 1300° or thereabouts. Within the tridymite range amorphous silica in fused sodic tungstate or alkaline silicate yields at first a mixture of cristobalite and tridymite, which later becomes entirely tridymite.

From 1470° upward to the melting-point any form of silica heated in a tungstate melt is changed into cristobalite. At 1500° and upward the reaction is fairly rapid.

At high temperatures quartz, heated without a flux, changes to cristobalite even below the tridymite-cristobalite inversion-point. The upper limit of this reaction is set by the melting-point of cristobalite. The lower limit is uncertain. A practical experimental limit is set by the length of time required. Fine grinding much increases the rate of reaction, but finely ground quartz heated 108 hours at 1250° ± showed only a small percentage of inversion. After 90 hours at 1360° ± the product consisted of about $\frac{2}{3}$ cristobalite and $\frac{1}{3}$ unchanged quartz. At 1570° the reaction is nearly complete in an hour.

At 1570° tridymite heated without a flux is converted to cristobalite.

At any temperature below the melting-point of cristobalite down to a limit only conditioned by the length of time required, amorphous silica (either glass or precipitated silica), heated without a flux, changes to cristobalite. At 1030° ± precipitated silica appeared completely changed after 69 hours' heating. (The change may have been complete in rather less time.)

LOW TEMPERATURE INVERSIONS.

The inversions so far discussed have been characterized by a complete change of crystal form. Under the most favorable conditions they take place slowly and with difficulty, and any of the species can be exposed to temperatures far exceeding the limits of stability without any abrupt change occurring. There is another class of inversions however, whose character is markedly different. There is no noticeable change in the outer form of the mineral in question, but some small rearrange-

ment of the internal structure befalls, attended by slight changes in the optical properties, and the transformation occurs promptly and at a definite temperature when the mineral is heated. On cooling, reversion follows with similar promptness, usually not at exactly the same temperature, but at only a few degrees lower. The fact that each of the minerals in question exhibited a phenomenon of this kind has been known for some time, but further investigation has brought out some new facts, which suggest an explanation of the radical differences between the two types of phenomena and have a bearing upon theories of the internal structure of the crystals.

The new phenomena are exhibited most prominently by cristobalite; hence the investigation of this mineral will first be taken up, and later the same sort of inquiry extended to quartz and tridymite.

The α - β Cristobalite Inversions.—Mallard* determined that upon heating cristobalite crystals the birefringence disappeared abruptly at a certain temperature, to reappear upon cooling. Above the transition point the crystals possessed the isotropic character consistent with their crystallographic form. The temperature was placed by him at 175°. Later, F. E. Wright† made a redetermination by heating in the thermal microscope plates of cristobalite cut from spherulites crystallizing in silica glass, and found that Mallard's determination was too low. He placed the temperature at approximately 225°. Recently, Endell and Rieke‡ have found by dilatometric methods a noticeable volume-change taking place at about 230°.

In my own work the problem appeared at first to be merely the determination of the inversion-point by methods as exact as possible. By the application of a very simple device (to be described immediately) it was found possible to determine the inversion-point in a manner which left nothing to be desired, but it was soon observed that the results obtained differed from each other most remarkably. Whereas the inversion-point of any given preparation determined under varying conditions gave results which agreed most satisfactorily, another preparation might differ by twenty or thirty degrees from the first. There was thus revealed a line of investigation which demanded attention, namely, the determination of the limits within which the temperature of inversion could be made to vary, and the factors influencing the variation; finally, the development of an explanation which would be in harmony with the observed facts, and the elimination of all other possibilities which could be conceived by showing that they were inconsistent in one way or another when put to the test.

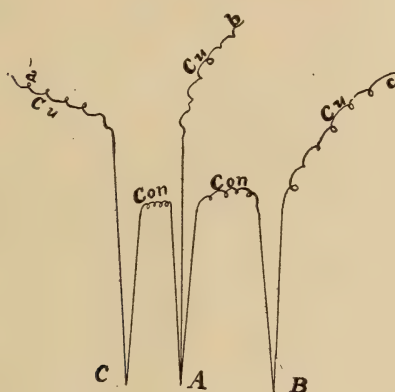
* E. Mallard, Bull. Soc. Min., xiii, 176, 1890.

† F. E. Wright, J. Ind. Eng. Chem., iii, 4, 223, 1911.

‡ K. Endell and R. Rieke, Zs. anorg. Chem., lxxix, 239, 1912.

The inversion from α - to β -cristobalite which occurs upon heating is perfectly sharp but is accompanied by a very small energy-change. Therefore the heating-curve method ordinarily applicable for the determination of a sharply defined transition-point is not adapted for this particular case. By means of a simple modification,* however, very precise measurements may be made. The essential feature of the appliance consisted of the use of two thermocouples, one of which was imbedded in the substance in question and gave directly its temperature in terms of electromotive force, and the second was imbedded in a neutral body which was exposed to the same temperature-treatment as the first, but underwent no transformation involving an

FIG. 5.



absorption of heat within the temperature range under observation. The two thermocouples were connected in such a manner that the electromotive force due to the temperature of one charge was opposed by that of the second, so that readings expressed differences in temperature between the two. The general arrangement is shown in fig. 5. The materials of the thermoelement wires were pure copper and the alloy constantan, whose electromotive force at different temperatures up to 360° has been determined by Adams and Johnston.† These metals give a much larger electromotive force than Pt against Pt-Rh, but can only be used for rather low temperatures.

In the arrangement shown in fig. 5 the element A is placed within the charge under investigation, and the ele-

* Due to W. Roberts-Austen. See G. K. Burgess, Bull. Bureau Standards, v, p. 210, 1908-9.

† L. H. Adams and J. Johnston, this Journal, (4), xxxiii, 534, 1912. The constantan wire used in making my own thermoelements was from the same bobbin as that used by Adams and Johnston for the calibration curve above published.

ment B in the ice-bath. Terminals *b* and *c* are connected to the galvanometer and give the temperature of A. C is placed within the neutral charge alongside of A, and the connections *a* and *b* give the difference in temperature between A and C. By means of a switch one may read first the current in *a-b* and then the current in *b-c* on the same galvanometer. As ordinarily carried out the temperature of A was read and noted every second minute during heating or cooling, and the difference A-C every half or quarter minute except at the two-minute points.

Under ideal conditions the neutral body should be of such a nature and so placed in the furnace that its temperature should be exactly equal to that of the other, and hence the temperature-reading between them should be zero up to the point at which the substance under observation begins to undergo transformation, which would cause its temperature to rise less rapidly than that of the neutral body. In practise this could not, of course, be realized absolutely, but it was not difficult to approach the ideal condition with satisfactory closeness.

Ordinarily the powdered cristobalite was placed in a thin-walled test-tube of about 10^{mm} diameter, and the junction A was imbedded within the powder. In a similar tube was placed a like amount of powdered quartz or feldspar inclosing B. The two tubes, placed close together but separated by an air-space, were symmetrically disposed in the furnace and the heating current turned on. As the temperature rose the differential reading showed some variation, which, however, was small and followed a smooth curve up to a certain point, after which the progress of transformation could be plainly perceived by an increasing magnitude of deflection. This rapidly reached a maximum and then fell back with equal rapidity. The graph of a typical heating and cooling curve has been plotted in fig. 6. The temperature at which the peak of the differential curve was attained was considered the temperature of inversion and its value was calculated by interpolation between the nearest temperature readings on either side. A linear interpolation under such conditions is not strictly correct, but the magnitude of the error, due to this source and to one or two others, which might be mentioned, is believed to be so small as to be negligible. In practice a repetition of determinations was frequently made under variation of conditions and gave closely concordant results. An agreement within 2° was common, and a variation of 4° was quite unusual. As the errors are not of such a nature as to be systematic, the limits found undoubtedly show the degree of approximation to the correct value. In the figures which are given later the calculated temperatures are expressed to the nearest tenth of a degree, but only the integers should be considered of real significance.

The results first obtained were much higher than those found by Mallard and Wright, and I was inclined to attribute the differences to foreign material taken up in solid solution, as the cristobalite which was being employed had been obtained from a tungstate melt. It was found, however, that the amount of variation was independent of the quantity of

FIG. 6.

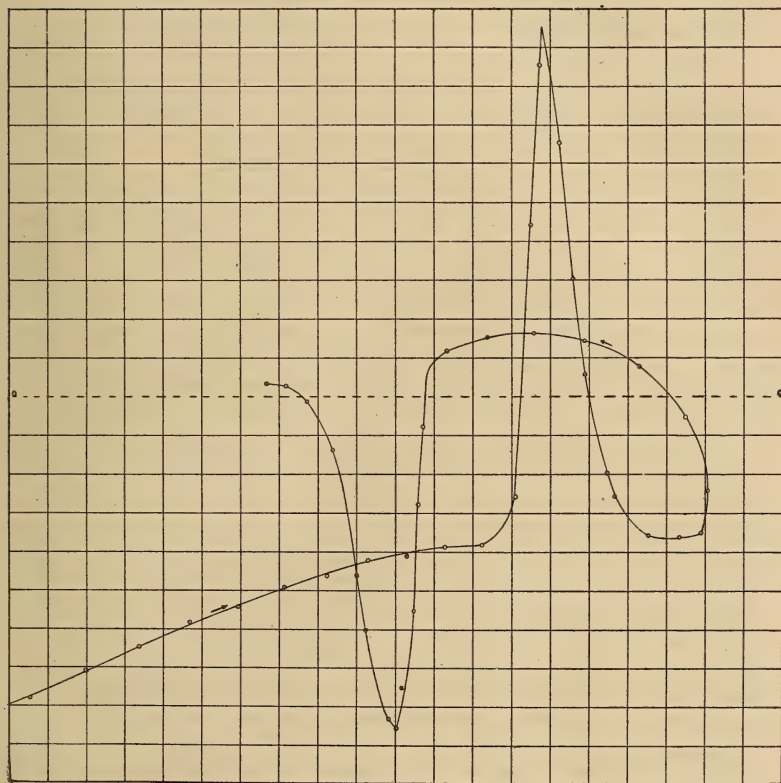


FIG. 6. Heating and cooling curve of the α - β cristobalite inversion. Temperature-differences plotted against temperatures.

Horizontal scale; 1 square = 500 microvolts (approximately 10°).

Vertical scale; 1 square = 20 microvolts (approximately 0.4°).

impurity shown by analysis, and the possibility was entirely eliminated by using cristobalite obtained by the inversion of almost chemically pure quartz at a high temperature without a flux. The quartz used for this purpose was specially purified material supplied by Baker and Adamson, which was shown

by a number of analyses to contain only 0.04–0.07 per cent impurity. The results from these preparations were no more concordant than before, and by further investigation it was brought out that we had to do with a phenomenon of a rather different nature from any which had been encountered in previous work in this Laboratory. After considerable preliminary experimentation the results began to point in a definite direction. A tentative hypothesis was formulated as a working basis and investigation was directed along the course indicated by this conception and tended to confirm it. As a final result it can be said that while absolute proof is lacking, the results obtained are perfectly in harmony with the conception and all other hypotheses which have presented themselves as possible explanations have been pretty well disproved.

Briefly stated the conception is this: that cristobalite consists not of one but of at least two different molecular species in the same crystal. The relative proportions of these depend upon the conditions present at the time of crystallization, such as the nature of the solution, if formed in a melt, or the temperature at the time of inversion, if formed in a dry way. The relative proportions of the polymeric molecules as fixed by the conditions of formation are not affected by cooling quickly to room temperatures, but by a second exposure to a high degree of heat a variation in the proportions is brought about by a transformation of some of the molecules of one kind into the other, and upon cooling again the properties are found to have become different in accordance.

It will be recognized that this is essentially the theory which A. Smits and his co-workers have urged strongly in the last three years in a series of papers appearing especially in the *Zeitschrift für physikalische Chemie*, and the *Proceedings of the Koninklijke Akademie van Wetenschappen at Amsterdam*,* and confirmation of this conception has been furnished by certain phenomena exhibited by mercuric iodide, sulphur, phosphorus, etc. Upon it a theory of allotropy has been founded. Smits' theory is a conception of great moment and it is important that all possible evidence should be brought to bear upon it. In this connection the properties of cristobalite appear to have some value.

The point of departure of Smits' theory is that investigation has shown that liquids, either pure melts or solutions, contain as a rule a given substance in two or more sorts of molecular aggregation, each of which is capable of transformation into the others by a change in the mode of linkage of the simple molecules, but the proportions of the various modifications are

* A. Smits, *Zs. phys. Chem.*, lxxvi, 421, 1911; lxxxii, 657, 1913; *Kon. Akad. v. Wet.*, Mar. 26, 1910; Sept. 30, 1911; Sept. 28, 1912. A. Smits and H. L. DeLeeuw, *Kon. Akad. v. Weten.*, Sept. 24, 1910; Nov. 30, 1912.

fixed for any given condition of equilibrium. From this it is but a short step to suppose that when a solid crystallizes from such a liquid not only one but two or several molecular species go to form it. The proportions of the several molecular species in the solid and liquid will differ from each other but a certain equilibrium will exist between the two phases. In the crystallization of such a system the substance in question *may* behave as a unary substance. This is accounted for by the fact that the condition of inner equilibrium in the melt, when disturbed by the appearance of a new phase, is immediately restored by the necessary transformation of molecular species, and in this manner equilibrium is constantly maintained. When, however, the molecular transformations are not accomplished with sufficient facility to maintain equilibrium under rapidly changing conditions, the binary or ternary nature of the substance will show forth. The crystallization of such a pseudo-unary substance will be analogous to that of mixed crystals and should show a similar temperature-range of crystallization. Inversions in the solid state should be characterized by similar phenomena. When inversion occurs the components of the pseudo-unary mix-crystals unmix, as Smits expresses it, and the temperature of inversion will depend upon the relative proportions of the two or more species of molecules as determined at the time of formation.

A further thesis as stated by Smits is "that this theory requires that every substance which shows a transition point must consist of two different kinds of molecules, which are in equilibrium at every temperature."* The necessity of this as a consequence of the main theory is not wholly evident and certain phenomena which will be described later tend to throw doubt upon its validity as a universal proposition. We may suppose that a liquid consisting of the molecular species λ and μ in the proportions demanded by equilibrium starts to crystallize, but that the requirements of the distribution of forces within the crystal-structure can be met only by the species λ . Then the crystallizing solid will withdraw λ only from the liquid, leaving a surplus of μ . This, however, will be met by a transformation of some of the μ molecules into λ until equilibrium is restored, and this process will continue until the whole has crystallized in λ molecules. Moreover such a crystal may possess an inversion-point. The process here will not be an *unmixing* of molecular species as Smits conceives, but it will be more probably a rearrangement of the one kind of molecule within the crystal structure due to the fact that the equilibrium of forces has become unstable when a certain

* A. Smits, Koninklijke Akademie van Wetenschappen te Amsterdam, Proceedings of Mar. 26, 1910 (English text).

has been formed at a very high temperature it will give a peak on the heating curve (such as shown in fig. 6) at about 270° , and on the cooling curve at about 240° ; if formed at successively lower temperatures these two points will drop step by step until at the lowest limit at which cristobalite has been produced the corresponding points are 220° and 198° , a drop of about 50° and 40° respectively.

If cristobalite is of the pseudo-unary but actually binary nature which has been suggested, the temperature-composition diagram should be of the general form shown in fig. 7.

In this the two kinds of molecules are represented by λ and μ . The proportions of these in equilibrium at different temperatures from A to B are given by the line AB, and the β - α inversions of the pseudo-unary mix-crystals are given by the curves CBD and CED. In the inversion of a β -crystal of the composition B a small amount of α -crystal of the composition E is first formed and by the continuation of inversion the composition of the β -crystal moves along BG and of the α -crystal along EF. At F the whole has been inverted. This diagram, however, represents merely a theoretical conception involving the requirement that equilibrium keeps pace with changes of temperature. With such a substance as cristobalite this requirement cannot, of course, be strictly fulfilled and the process will vary in accordance. The composition of the material formed at any temperature such as A or H will be reached only after very long heating, if at all. It is found, in fact, that the actual composition (that is, relative proportions of λ and μ molecules) of the material formed at any given temperature depends upon the nature of the material with which we start. If quartz is employed at the temperature H a composition I is attained, if amorphous silica, a composition K. This is not surprising, if we consider that in the one case we are approaching the composition H from a lower form, and in the second case from a higher. The inference is that the quartz molecule, in breaking up, forms at first relatively more of the lower (λ) molecule than does amorphous silica at the same temperature. The velocity of reaction in converting one kind of molecule into another is so slow (as are all changes throughout the silica diagram which involve the formation of new molecules) that the composition which, at the temperature H, should be represented by the point H on the AB line, is actually represented by the point I in one case and the point K in the other. Moreover, after the material has once been formed and its composition fixed it retains it during cooling. Indeed it is from this fact that differences of composition can be recognized, for material of the composition K', when cooled, will still retain this composition (instead of changing along K'B) and will give the β - α inversion corresponding to

the point K' . For this reason, also, only a small portion of the compositions represented by AB can be realized, that is, the compositions corresponding to very high temperatures. It has been found, however, that if material corresponding in composition to I' , whose β - α inversion temperature is determined, is placed again in the furnace at the temperature K' , a well-marked tendency to change to the composition K' is shown by a shift in the inversion-point toward the right. Likewise material of the composition K' can have its composition shifted toward the left by a second heating at a lower temperature.

In another respect the course of the β - α inversion differs from the theoretical course first outlined. Upon cooling material of the composition represented by K the transformation from the β to the α form might be supposed to start at K'' and be spread throughout the range of temperature from K'' to K''' . There is, however, some undercooling, as is often found in transformations in solids, and the temperature K''' or possibly even a little lower temperature is reached before transformation starts and then the whole transformation goes off at once. Upon the heating-curve also there is a similar delay and the temperature rises to K'' or above before transformation occurs.

These variations from the simple diagram are easily explained and do not obscure the broad, general fact of great variations in the temperatures of inversion produced by previous heat-treatment.

In Table I, I have collected the experimental data which have a bearing upon the matter.

These tabulated figures bring out in a striking manner the general decrease of the α - β inversion temperature with decrease of the temperature to which the material has been previously exposed. The irregularity introduced by the tendency of material made from amorphous silica to give higher figures than quartz is also quite evident. Cristobalite formed in a tungstate melt, it may be noticed, shows similarity to that from amorphous silica rather than to that from quartz.

A certain source of irregularity requires a few words of explanation; that is, that two preparations which give closely coincident inversion-points on heating may differ a number of degrees in the cooling temperature. I think this may be due, in part at least, to some slight variation in composition (proportion of λ and μ molecules) among different crystals in the same preparation. Frequently a sample of cristobalite formed by the inversion of quartz shows still an occasional grain of unchanged quartz, and it seems likely that there should be various degrees of transition between such an unchanged remnant and crystals whose composition is far advanced toward the equilibrium demanded by the temperature to which they have been

TABLE I.

Temperature of α - β Inversions of Cristobalite, showing effects of previous heat-treatment.

Method of formation of the cristobalite	Inversion temperature on heating	Reversion temperature on cooling	
No. 108. Made by heating finely ground purified quartz with Na_2WO_4 at 1580°	(a) 272.1° (b) 273.6°	272.8°	238.5° -----
No. 111. Same as above, at 1570°	(a) 274.5° (b) 272.5° (c) 276.9°	274.6°	238.1°
No. 158a. Produced by heating fine-grained cristobalite with Na_2WO_4 over blast-lamp. Is mixture of tridymite and cristobalite crystals	(a) 272.1° (b) 272.0°	272.0°	231.9° 233.5° 232.7°
No. 179. From ground quartz heated in Fletcher furnace about 40 min. at $1640^\circ \pm$		268.2°	240.5°
No. 116a. Made by devitrifying SiO_2 glass without flux at 1600°		271.1°	234.3°
No. 116b. From large quartz crystals without flux at 1600°	(a) 264.8° (b) 263.5°	264.1°	233.2° 233.7° 233.4°
No. 124. From finely ground quartz without flux at 1580°	(a) 261.7° (b) 260.8° (c) 261.6°	261.4°	231.4° 232.8° 232.1° -----
No. 168. Made by heating tridymite without flux at $1580^\circ \pm$		268.3°	238.2°
No. 160a. From finely ground quartz without flux at 1580°	(a) 259.9° (b) 262.6°	261.3°	231.5° 229.3° 230.4°
No. 134. From purified quartz without flux at melting-point of platinum		259.9°	232.3°
No. 125. From amorphous precipitated silica without flux at 1450°		258.5°	229.1°
No. 183. From devitrification of silica glass at $1360^\circ \pm$ for 93 hours	(a) 258.5° (b) 255.1° (c) 257.0°	256.9°	218.5° 217.2° 217.8° -----
No. 126. From ground quartz without flux at 1510°		248.0°	224.5°
No. 121. From ground quartz without flux at 1470°		240.1°	218.8°
No. 133. From finely ground quartz heated 66 hours at 1300° - 1400°		232.5°	209.2°
No. 142. From amorphous precipitated silica heated 70 hours at $1100^\circ \pm$		230.8°	207.2°
No. 175. From amorphous precipitated silica heated 69 hours at $1030^\circ \pm$		225.1°	205.1°
No. 184. From ground quartz heated without flux $90\frac{1}{2}$ hours at $1360^\circ \pm$	(a) 229.5° (b) 229.1°	229.3°	213.8° 212.9° 213.3°
No. 166a. From silica glass heated 68 hours at approximately 1025° - 1075°		219.7°	198.1°

exposed. In inversion the effects due to the different components of such a mixture would be superposed upon each other and could not be distinguished.

Mention has been made of the fact that the temperatures of inversion-points can be changed by heating the sample a second time at a temperature different from that at which it was first prepared. This is shown by the following figures:—No. 142 was prepared from amorphous precipitated silica heated 70 hours at $1100^{\circ}\pm$. Inversion-points 230.8° and 207.2° . After reheating at a high temperature (probably 1500° – 1600°) in a Fletcher gas furnace the inversion-points were 267.5° and 235.5° . No. 175 was from amorphous silica at $1030^{\circ}\pm$ for 69 hours. Inversion-points 225.1° and 205.1° . After reheating to 1570° the inversion-points were 258.3° and 217.6° . No. 166a was made by devitrifying silica glass at approximately 1025° to 1075° . Inversion-points 219.7° and 198.1° ; after heating to 1580° , 258.2° and 225.8° .

When the temperature of the first heating was high the effect of a second heating at a lower temperature was not so striking, though still noticeable. No. 172 was prepared at 1580° and gave inversion-points 268.8° and 226.9° . After reheating 46 hours at $1200^{\circ}\pm$ the points were 263.8° and 227.6° .

From the data which have been assembled there is hardly room for doubt that the position of the inversion-points is dependent upon the previous heat treatment, and the behavior of the material seems to be perfectly consistent with the theory that the crystals are composed of two different molecular species. It remains to be shown that other explanations which have been conceived as possible are not competent to explain the facts when put to the test. There are a number of these possibilities with a greater or less degree of apparent probability.

1°. The variation may be due to foreign material in solid solution. This has already been discussed and its impossibility pointed out.

2°. The effect may be due to differences in lag in the α - β inversion. This was considered as a possible explanation before the amount of variation was known. When it was discovered that the inversion on cooling with some preparations was above that on heating with others, this possibility was eliminated. Before this, however, evidence of another sort had been obtained. It was found that large variations in the rate of heating or cooling made no observable change in the inversion-points. Furthermore, a certain preparation which gave a break at 272.1° on heating and 238.5° on cooling was heated to 320° , then cooled slowly, holding for $1\frac{1}{4}$ hrs. at 247.5° – 244.4° (9° to 5.9° above the lower inversion-point). The temperature was then allowed to drop and the break found at 238.0° , practically the same as before. Heating from room-temperature

and holding for an hour at 7° below the upper inversion-point likewise failed to produce inversion. With the same preparation a device was arranged by which a platinum wire passing through the charge could be brought to a red heat by an auxiliary current at any instant. This would, of course, convert the material immediately in contact with it from the α to the β form and might induce transformation in the remainder of the charge at a lower temperature than before. The auxiliary current was applied at different points during heating, but transformation of the charge as a whole did not occur until 269.1° was reached, which, within the limits of error, may be considered the same point as before.

Probably there is some lag-effect, but so small in amount as to be almost negligible.

3° . The effect may be due to differences in fineness of material. With very fine material, size of grain is a theoretical factor, as the amount of free energy involved in passing from the α to the β form is dependent upon it. Because of the small total energy-change involved in the inversion, any means by which the amount of free energy of one form over that of the other was changed might be conceived to have a large effect in shifting the inversion-point. Experiments were made to determine the amount of the effect which fine grinding would produce, and the results seemed to show that the inversion-point might be shifted a few degrees by this means, but that nothing approaching the differences of 40° or 50° which had been attained could be produced by this process. A certain preparation (No. 160a) gave inversion-points at 261.3° and 230.4° . A portion of this, which was so fine as to settle from suspension in water only after long standing, gave 262.0° and 227.3° . Another portion was ground for about 35 hours in a mechanically driven mortar, being kept moist with kerosene. At the end the grains were so small that they were almost beyond the resolving powers of a No. 9 objective. The kerosene was driven off by gentle heat and the resultant powder gave inversion-points at 259.6° and 218.5° .

Another preparation was divided into two portions by a 200-mesh sieve. The coarser portions gave inversions at 266.4° and 236.0° . The portion which passed through was further ground in a mortar and gave inversions at 271.2° and 231.3° .

Several experiments gave similar results. There is evidently some effect, but its nature may be an increase of the lag in inversion rather than a real shift of the inversion-point, and in any case the effect is of rather a minor order.

4° . The effect may be due to variations among different preparations in the size of the twinned areas in the α form. If one preparation in passing from the isotropic to the birefringent state gave rise to large twinned areas, and another to

small, forces of surface energy would come into play and might produce analogous effects to those considered under 3°. But it was found, as shown above, that surface energy is not an important factor in displacing the inversion-point. However, it was thought desirable to see if any perceptible change could be effected by great variations in the rate of cooling through the inversion-point. The preparation selected gave inversions at 266.2° and 236.2°. A portion was heated 16 minutes at 416°–377° and then plunged directly into water. It gave 265.6° and 235.4°. The same charge was heated to 308° and then held overnight at about 270°. It was then cooled and inversion-points determined. Results were 262.4° and 237.4°. The charge was then heated to 286° and cooled very slowly, requiring three hours to pass from 280° to 229°. The inversion-points were then 266.2° and 236.7°. Apparently, therefore, no treatment of this kind had any effect in changing the temperature of inversion.

5°. As an efficient cause an hypothesis might be considered which seems rather far-fetched but which should be taken into account; that is, that the high-temperature form which appears to be isometric is in reality the same as the low-temperature form, the apparent high degree of symmetry being due to sub-microscopic twinning. Under this conception the so-called inversion-point would be merely a point at which the sub-microscopic areas suddenly grew to perceptible size. This possibility, however, seems inherently improbable from our general knowledge of crystal structure and is further controverted by the crystal characteristics of the α and β forms as described on p. 355. It was shown there that not only is the exterior form of the high-temperature cristobalite consistent with isometric symmetry, but that the manner in which the axes became twinned during growth showed twinning after the spinel law, and gave angles of 45° and 60° between adjacent portions of the axes. In the low-temperature form, on the other hand, the twinning was around a 45° pyramid and caused the axes to assume positions at 90° with each other.

As a result of the investigations on the α and β inversions of cristobalite, we appear to be brought to the conclusion that the variations are due to the presence of two or more molecular species in the mineral, whose proportions are conditioned by the previous heat treatment. Certain minor variations arise from other causes, but their magnitude is so small that the main effect is not seriously obscured thereby.

THE LOW-TEMPERATURE TRIDYMITÉ INVERSIONS.

The method used for the determination of the temperature of the tridymite inversions was the same as has been described

for cristobalite; that is, a differential method by which the differences in temperature between the tridymite charge and a neutral substance were read. Previous work with natural tridymite had shown that there was a change in optical properties at a temperature which had been placed at about 130° ; and the intention was to determine this point rather more accurately. It was found, however, that when the curve of temperature-differences against temperatures was plotted, two well-defined breaks were revealed, as shown in fig. 8. It was then considered desirable to investigate this phenomenon more closely and to determine the properties of tridymite formed under varying conditions and ascertain whether the two points were always shown and whether their temperatures were constant. The results are given in Table II.

FIG. 8.

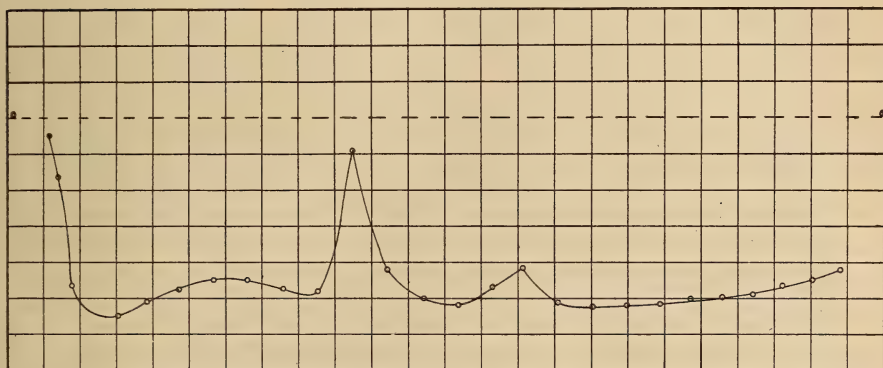


FIG. 8. Heating curve of the α - β_1 - β_2 tridymite inversions. Temperature-differences plotted against temperatures. Horizontal scale: 1 square = 500 microvolts (approximately 10°); vertical scale: 1 square = 10 microvolts (approximately 0.2°).

From this table it will be seen that variations in conditions of formation appear to have no effect upon the inversion. The two breaks always appear and the temperatures are practically constant.

A number of attempts were made to determine by the same method the corresponding breaks on the cooling curves, but nothing which seemed significant could be detected. In order to ascertain the reason for this, optical methods were resorted to. Several tridymite crystals were taken from a specimen of rock from Cerro San Cristobal, which the U. S. National Museum kindly furnished us. These were placed on a glass slide, immersed in a heavy oil, and a cover slip placed above. The slide was laid above a hole in a heavy copper bar on the

TABLE II.

Inversion Points of Tridymite formed under varying conditions.

Method of formation		Temperature of inversion No. 1		Temperature of inversion No. 2	
No. 112.	Quartz and Na ₂ WO ₄ heated to 1000° ± for 118 hours.....	(a) 116.2°	117.7°	164.0°	162.4°
		(b) 119.2°		160.9°	
No. 106.	Quartz and Na ₂ WO ₄ heated to 1000° ± for 71 hours.....	(a) 117.6°	118.1°	161.7°	161.4°
		(b) 118.7°		161.2°	
No. 144.	Quartz and Na ₂ WO ₄ heated to 1300° ± for 3 hours.....	(a) 117.6°	117.3°	165.6°	165.2°
		(b) 117.0°		164.7°	
No. 155.	Mixture of quartz, tridymite and cristobalite made from amor- phous, precipitated SiO ₂ with Na ₂ WO ₄ over Bunsen burner.....	117.1°		162.9°	
No. 159b.	Precipitated SiO ₂ and Na ₂ WO ₄ heated over blast. Some cristobalite formed at same time....	115.2°		162.2°	
No. 173.	Precipitated SiO ₂ and Na ₂ WO ₄ heated 41 hours at 870° ± ..	118.4°		162.5°	
Average.....		117.4°		162.8°	

stage of a microscope, and the ends of the bar were heated by burners. Heating was equalized by covering the bar with sheets of asbestos. The approximate temperature was given by a thermoelement resting against the bottom of the slide. By this means heating and cooling could be conducted rapidly or slowly. In addition to observations on cooling phenomena a close watch was kept during heating to see if any observable change occurred at the second inversion-point. Several experiments were made, running the temperature up to 200° or more and then allowing it to drop. The results were practically identical in each instance. At a temperature of about 120° , on heating, the faint birefringence of a basal section suddenly disappeared. From this temperature on up to 200° (or as far as heating was carried) nothing further could be detected either on isotropic basal sections or on slightly birefringent tilted sections. Upon cooling, the first change noticeable took place considerably below 120° and was not so abrupt as upon heating. At about 90° basal sections began to show a little birefringence, and at 70° to 65° the reversion was apparently complete.

From these results it is inferred that the optical changes attendant upon the second inversion are of a very low order, and that reversion upon cooling occurs considerably below the point obtained on heating and is spread over a range of temperature. For that reason no break can be detected upon the cooling curve by the methods first employed.

In the absence of direct evidence an opinion upon the significance of the second inversion-point (at 163° ca.) is some-

what speculative, but a suggestion may be made as to the probable nature of the phenomenon. This inversion may very well be analogous to that of quartz in passing from the α to the β form. The latter has been supposed to be a change from tetartohedral to hemihedral symmetry within the hexagonal system. With tridymite the change may be one from hemihedral hexagonal to holohedral hexagonal.

The low temperature form of tridymite has been called α -tridymite, and I have adhered to this usage, although it is contrary to the usual custom, which applies the term α to the highest form. The term β -tridymite, it seems now, covers two forms, which it is necessary to distinguish. The system of nomenclature which is in use is not well adapted to meet such a contingency, and I can only suggest that the form stable between 117° and 163° be called β_1 -tridymite and the form stable above 163° be called β_2 -tridymite.

It was seen in the case of cristobalite that the experimental phenomena observed in the inversion from the α to the β form seemed to necessitate a conception of two different sorts of silica molecules within the crystal. As a consequence, the temperature of inversion could be made to vary over a wide range by changing the conditions of formation. With tridymite nothing of this nature can be detected. The temperatures of the two inversions appear to be fixed, whatever the temperature of formation and whether quartz or amorphous silica be employed at the start. Even under conditions of formation of such a nature that quartz, tridymite, and cristobalite are simultaneously precipitated from a melt (as in Exper. 155, Table II), implying the presence of several kinds of molecules in solution at the same time, the tridymite obtained gives temperatures of inversion coinciding with those given by other samples. It seems probable, therefore, that the nature and distribution of forces within a tridymite crystal are such as to admit only one kind of molecule, and in this respect tridymite differs from cristobalite. The supposition might be made that two kinds of molecules are present in tridymite but that equilibrium is maintained by a sufficiently rapid transformation of one kind of molecule into another to keep pace with changes of temperature. A strong argument against this hypothesis is the general reluctance manifested in the transformations of silica molecules.

The low-temperature forms of tridymite and cristobalite are somewhat unique. Although the reaction α -cristobalite \rightleftharpoons β -cristobalite, for instance, is perfectly reversible α -cristobalite has no stable existence and its relation toward quartz is that of monotropy. The same is true of α - and β_1 -tridymite. In this respect the reactions of sulphur are quite analogous.*

* R. Brauns, Neues Jahrb., Beilageband, xxxix, 1900.

The α - β Quartz Inversion.

This inversion has been the subject of considerable investigation since the phenomenon was first observed by Le Chatelier in 1890. The attendant changes in expansion coefficients, circular polarization, and birefringence have all been studied, and O. Mügge* has been able to show by means of etch-figures combined with crystallographic reasoning that the inversion signifies a change from tetartohedral hexagonal to hemihedral hexagonal symmetry, the axial ratios of the two forms being

FIG. 9.

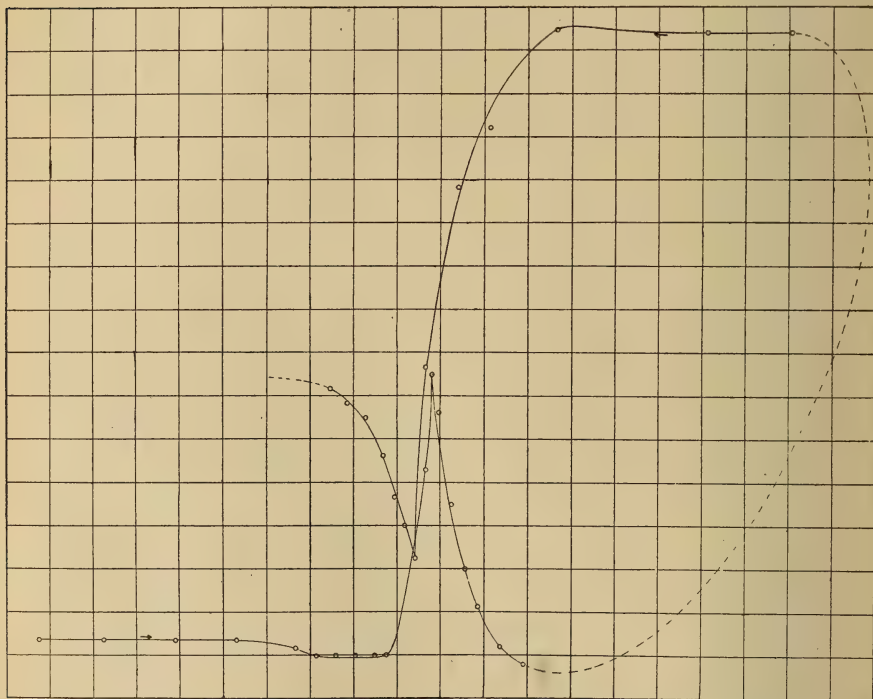


FIG. 9. Heating and cooling curve of the α - β quartz inversion. Temperature-differences plotted against temperatures. Horizontal scale: 1 square = 200 microvolts (approximately 20°); vertical scale: 1 square = 6 microvolts (approximately 0.6°).

nearly identical. Quite recently Wright and Larsen† have extended Mügge's work and have shown that the possibility of distinguishing between α and β forms gives to quartz considerable value as a geologic thermometer. The temperature of inversion as determined in a thermal microscope is given as $575^\circ \pm 2^\circ$.

* O. Mügge, *Neues Jahrb., Festband*, 1907, 181-196.

† F. E. Wright and E. S. Larsen, *this Journal*, (4), xxvii, 162, 421-447, 1909.

The subject of this inversion has been so thoroughly studied that there seemed to be little to be added. The chief point to which the writer directed his attention was the possibility of finding a variation in the temperature of inversion similar to that which is so well marked in cristobalite.

The method of determining inversion temperatures was the same as that used for cristobalite and tridymite, but the higher temperature prohibited the use of copper-constantan thermoelements and the standard Pt—Pt Rh elements were substituted. The sensitiveness of these is only about one-fifth that of copper-constantan and the accuracy of determination was slightly diminished, nevertheless very satisfactory results were obtained. The form of curve is shown in fig. 9.

In general, natural quartz of different modes of occurrence was employed, but artificial material obtained by the conversion of cristobalite in a tungstate melt at 800°–835° was also used, and in addition determinations were made on the pure quartz of the Laboratory stock previously heated to very high temperatures. All the results with one exception were almost identical. With this one exception, they are tabulated below.

TABLE III.
Inversion Temperatures of Quartz.

Material used	Inversion on heating		Reversion on cooling	
1. Ground quartz, Laboratory stock, } untreated..... }	(a) 576.4°	575.9°	570.7°	571.5°
	(b) 575.5°		572.3°	
2. Same, heated over Bunsen.....	576.6°		-----	
3. Same, heated 11 minutes at 1515°-- } }	(a) 572.7°	573.2°	567.8°	569.1°
	(b) 573.7°		570.4°	
4. Same, heated 10 minutes at 1527°-- } 1543° and cooled slowly..... }	573.4°		567.9°	
5. Same, heated 20 hours at 1200°±.....	574.7°		571.1°	
6. Quartz phenocrysts from granite } near Meissen..... }	575.6°		569.7°	
7. Amethystine quartz from Paterson, } N. J. }	575.2°		569.3°	
8. Milky quartz from Dutchess Co., N. Y.	575.1°		568.9°	
9. Crystals of water-clear quartz from } Moritz Co., N. Y., showing right } trapezohedron..... }	574.5°		567.2°	
10. White quartz from pegmatite vein, } District of Columbia..... }	574.6°		571.2°	
11. Rose quartz from near Paris, } Maine..... }	(a) 574.4°	574.1°	569.5°	
	(b) 573.9°		-----	
12. White quartz from a pegmatite } vein, Maine..... }	574.5°		569.7°	
13. Abnormal-looking green quartz } from Copper Mt., Alaska..... }	574.1°		570.2°	
14. Artificial quartz made from cristo- } balite in a tungstate melt..... }	(a) 577.1°	577.2°	568.9°	568.5°
	(b) 577.1°		568.2°	
	(c) 577.5°		568.5°	
Average.....	574.9°		569.5°	

The average of all determinations gives practically the figure 575° for the inversion-point on heating, and 570° for the point on cooling. The very slight variation from these figures given by any sample, whatever its mode of origin or previous treatment, indicates the presence of but one sort of molecule in quartz-crystals, but an element of doubt enters into the question because of the anomalous behavior of one sample not listed above. This material was from a quarry in basalt at Paterson, N. J., and was associated with zeolites. The quartz was doubtless deposited from aqueous solution at a comparatively low temperature. The material collected consisted of separate crystals, $\frac{1}{2}$ cm. in length, perfectly clear and colorless at top, a little milky at base. A little scaly hematite in small aggregates was present. The amount of material unfortunately was not large. Although the crystals all presented the same appearance, it appears probable that some were of normal quartz, as the results from different samples were not strictly identical, though consistently different from the usual values. The amethystine quartz listed as No. 7 in Table III was from the same quarry and collected at the same time.

The first sample of the abnormal material gave for inversion points 567.3° and 556.4° . A second gave (a) 564.4° and 559.8° (b) 564.7° and 559.7° . After heating 3 to 4 hours over blast it gave 564.5° and 560.0° .

A third sample was then taken and subjected to various treatments in the endeavor to obtain evidence as to the cause of the abnormal results. The material was ground very fine in a mortar and heated with concentrated HCl for several days on a steam bath. It was then washed and dried and inversion determined. Next it was heated at 1400° for 17 minutes and inversion again determined. The results were as follows:

Untreated material.

(a)	569.1°		558.2°	
(b)	568.5°	568.8°	555.6°	556.9°

Treated with HCl.

(a)	566.3°		560.5°	
(b)	564.9°	565.2°	559.9°	560.2°

Treated with HCl and heated to 1400° .

(a)	566.5°		561.8°	
(b)	567.8°	567.1°	557.8°	559.4°

The variations are not large and apparently the treatment to which the material has been subjected has not effected any significant change in the inversion-point. In the absence of evidence no definite conclusion can be drawn as to the cause of the abnormality. It seems most probably due to foreign

material in solid solution. The presence of a second molecular species of silica in the crystals is a possibility, but the normal behavior of other quartz from the same locality is opposed to this explanation.

Quartz in Pegmatites.—The criteria for distinguishing quartz formed above 575° from that formed below this temperature, which Wright and Larsen have developed, have enabled these writers and E. S. Bastin* to show that the quartz of pegmatite veins has frequently been formed in the neighborhood of the 575° inversion-point. This may be, in part, merely a coincidence, but it may be suggested that the contraction of the quartz in siliceous masses when cooling through the inversion temperature may be a contributing factor. Recent unpublished work by R. B. Sosman in this Laboratory has shown that in cooling from 600° to 550° the volume of quartz decreases about 2 per cent. This rather sudden contraction being superposed upon the normal contraction which a mass of quartziferous igneous rock undergoes in cooling will favor the development of fissures and their subsequent filling at about the inversion temperature.

Two types of Silica Inversions.—We have seen that the inversions of silica belong to two radically different types. One is distinguished by a small energy-change, small change of optical and crystallographic properties, and readiness of reaction; the other by a much greater change of optical and crystallographic properties, by sluggishness of reaction, and by energy-changes probably of considerable amount. The evidence which has been presented suggests an explanation of the differences. It points to the conclusion that in inversions of the first type the process is simply a small rearrangement of the molecules within the crystal-structure; in those of the second type the change is much more radical and involves the destruction of one sort of molecular species and the formation of another.

RELATIONS OF CHALCEDONY TO OTHER FORMS OF SILICA.

Evidence on the relations of chalcedony to quartz has been mostly of an optical character. The difficulties in the determination of the optical properties of fibrous chalcedony have been so great that no really conclusive proof of identity or lack of identity with quartz has been forthcoming. Arguments on both sides have been presented and at the present time the question seems to be largely a matter of personal opinion among those mineralogists who adhere to one side or the other. Some thermal work has been done by Le Chatelier and the results are frequently quoted, but careful study shows that they are

* Wright and Larsen, op. cit., pp. 446-447. E. S. Bastin, Jour. Geol., xviii, 4, 310, 1910.

very difficult of interpretation and can hardly be considered as evidence. Frequently the specimens of chalcedony were given a preliminary heating and only those which did not become badly cracked were used in the experimental work. The degree of heating is important but is seldom mentioned. In one case,* however, rods of chalcedony whose expansion was to be determined were placed in a porcelain-furnace at 1500° . This naturally converted the chalcedony into cristobalite, and the sudden increase in expansion between 170° and 245° which he found is what would be expected. Le Chatelier speaks of the uncertainty† caused by the multitude of fissures which traverse the specimens after heating and affect the results. I have replotted the values given for a number of experiments and am not able to perceive any definite evidence of sudden expansion corresponding to that of quartz at 575° .

As quartz gives a plainly-marked break on the heating and cooling curves when passing through the inversion-point, chalcedony should give similar breaks if it is identical with quartz. To determine this a number of samples of chalcedony were tested in the manner described under quartz. The specimens were from various localities. One was from the state of Chihuahua, Mexico, another from Tampa Bay, Florida, and a third from Kerguelen Island. The appearance of all was that of typical chalcedony. They were nearly transparent, waxy, and of a botryoidal form, and under the microscope showed a finely fibrous development. The details of experimentation were made precisely the same as for quartz. Heating and cooling curves were run and the region on both sides of 575° was carefully explored, but no indication of a break in the curves was perceptible.

In another form of investigation powdered chalcedony from the localities mentioned was mixed with sodic tungstate and heated at a temperature of 750° to 850° . It will be remembered that amorphous silica, when so treated, gave tridymite at first and quartz later, and the reason for this has been discussed. For the same reason chalcedony, if unstable at these temperatures, might be expected to act similarly, but if it is the same mineral as quartz no change could be expected to occur except that quartz crystals might conceivably grow to a larger size in the melt. In all cases the result was that new quartz crystals were formed and usually tridymite also, often in great abundance. If only a small amount of tridymite were formed under such conditions its origin might be attributed to intermixed amorphous (opaline) silica in the original chalcedony, but the quantity is so large that this hardly seems possible.

* Le Chatelier, *Compt. rend.*, cxi, 123, 1890.

† Le Chatelier, *ibid.*, cviii, 1046, 1889.

The behavior of chalcedony in the thermal microscope has also been studied. A thin section was ground, approximately parallel with the fibers, and carefully polished on both sides so that there was almost no surface diffusion. This was placed in the thermal microscope and the temperature raised rather slowly. The birefringence was observed carefully, especially through the tridymite, cristobalite, and quartz inversion temperatures. No sudden change in birefringence was perceptible up to 725° . There the section began to break up and at 820° was badly cracked, though certain areas were still quite clear. It was then cooled to 400° and no change of significance was observed.

All the work done upon chalcedony failed to show any relationship with quartz, and its conversion into tridymite at 800° to 850° points strongly to its being a different mineral.

Natural occurrences of chalcedony indicate its formation at rather low temperatures, but the evidence is not yet sufficient to decide whether it is stable under the conditions of formation or whether it is an unstable form whose precipitation is due to some peculiarity of conditions.

FUSION OF CRISTOBALITE AND QUARTZ.

In the former work of Day and Shepherd* the melting-point of silica was placed at approximately 1600° . The determination was made by exposing powdered quartz in an iridium furnace to various temperatures determined by an optical pyrometer, and observing the lowest point at which evidences of melting could be established. Under the conditions of experiment there may be a question as to whether the melting point of quartz or of cristobalite was realized. Lately Endell and Rieke† have made a new determination by heating cristobalite in an iridium resistance-furnace, temperatures being measured by means of a carefully calibrated Ir—Ir Ru thermoelement. They place the melting temperature at $1685^{\circ} \pm 10^{\circ}$. Although their work shows evidence of great care the results are not free from suspicion because of the high volatility of iridium at these temperatures and the possibility of contamination of the thermoelements, for which proper allowance cannot be made.

In making a new determination I employed a carbon-resistance furnace through which a current of carbon-monoxide gas was continually passing. Through the middle of the furnace an inner tube of magnesia was placed and a rapid current of dry air passed through it. By this means the atmosphere in contact with the carbon walls was kept of a reducing character, while the inner tube in which the thermoelement and charge

* A. L. Day and E. S. Shepherd, this Journal (4), xxii, 265, 1906.

† K. Endell and R. Rieke, Zs. anorg. Chem., lxxix, 239-259, 1912.

were placed was filled with an oxidizing atmosphere. Thus the contaminating effect of a reducing atmosphere upon the thermoelement was obviated. The charge consisted of a small pinch of cristobalite powder (made from specially purified quartz) wrapped in platinum foil and attached by wires to a standard Pt-Pt Rh thermoelement in direct contact with the junction. Any desired temperature could be attained in a few minutes and kept nearly constant for as long a time as wished. After exposure to the desired temperature the thermoelement and attached charge were withdrawn and the powder was examined under the microscope for indications of the formation of glass.

The reluctance in fusion was so great that length of heating was found to be an important factor. At first a period of fifteen minutes was supposed to be ample and a temperature between 1680° and 1690° was determined upon as that of fusion. Then the effect of longer heating was tried and the previous determination was shown to be too high. In all the later experiments heating was prolonged for half an hour and the lowest temperature at which a minute quantity of glass could be detected was considered to be the temperature of fusion. At a temperature of 1640° (uncorrected) the amount of glass was small, but could be plainly seen; at 1630° most of the grains were unaltered, but a few showed a little glass in minute ridges; at 1620° glass was believed to be visible, but there was a little uncertainty.

A check on the accuracy of the thermoelement was maintained by two calibrations, one made during the course of the experiments and one immediately after their close. The temperature of the furnace was run up to the point at which the platinum wire of the element fused, and the observed reading compared with the correct reading for the melting point of platinum. In one case the reading was 10° low and in the other 13° low. It is evident, however, that the correction to be applied is not of this magnitude, for the same contamination which caused the reading to be too low caused the wire to melt below the true melting temperature of platinum. It seems probable, on the whole, that the readings were not more than 5°-6° low, and I have, therefore, placed the fusing point of cristobalite at 1625° as derived from these experiments.

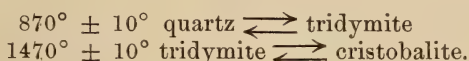
From theoretical considerations the temperature of fusion of quartz should be less than that of cristobalite. There was a question, however, whether the velocity of transformation to cristobalite might not equal that of fusion and prevent the experimental realization of the melting-point of quartz. To try this a quantity of ground quartz (Laboratory stock—0.04-0.07 per cent impurity) was placed in a platinum bucket suspended from a Marquardt tube. A thermoelement was imbedded in

the charge. The furnace having been brought to a constant high temperature the bucket of quartz was introduced and maintained at the same temperature for 30 minutes to 1 hour. After exposure to 1530° for 30 minutes the mass was tightly sintered. Microscopic examination showed the quartz grains to be bordered by a band of appreciable width, whose index was generally less than 1.475 and in some instances less than 1.465; it was isotropic to faintly birefringent; and consisted apparently of a mixture of glass ($n=1.460$) and cristobalite ($n=1.485$). After exposure to 1470° for one hour in another experiment the mass was likewise tightly caked. When immersed in a liquid of index 1.485 many of the quartz grains were seen to be surrounded by a narrow border of distinctly lower index. This same material also cut across many grains, leaving detached portions of crystals, and caused an irregular pitting and corrosion of others. It was found to be generally faintly birefringent and was probably a mixture of glass and cristobalite. That it was not entirely cristobalite was shown by the fact that it could be discerned in liquids of successively lower index—1.480, 1.475, and 1.470 . In liquid 1.465 it appeared in most cases to have a higher index than the liquid, but several good cases were found in which the index was lower and the material was isotropic. It appears, therefore, that the fusing-point of quartz is lower than 1470° , but that at this temperature it passes into cristobalite almost as rapidly as it melts.

The fusing-point of tridymite should lie between those of quartz and cristobalite. The artificial material obtained from tungstate melts always retains a small amount of the flux, which would affect the melting-point, and no attempt was made to determine it.

SUMMARY.

The relations between the mineral species quartz, tridymite, and cristobalite have been found to be enantiotropic. The inversion-temperatures under atmospheric pressure are



The velocity of transformation of one form of silica into another has been found to be very slow and in many cases the process follows Ostwald's rule; that is, an unstable form does not pass directly into the most stable form, but the action progresses through successive steps, and intermediate phases appear, which eventually reach the stage of greatest stability. The appearance of unstable phases in this manner has suggested an explanation of natural occurrences of tridymite and cristobalite under such conditions as preclude the idea of their

deposition within their range of stability, and an inquiry has been directed toward the circumstances attending their formation.

The preparations of artificial tridymite and cristobalite which have been made have yielded the minerals in very pure form and a re-determination has been made of a number of their optical and other physical constants. The relations of chalcedony have been investigated and evidence has been obtained tending to show that it is a distinct mineral species.

New determinations of the α - β inversions of the several species have given the following results:

$$\begin{cases} \alpha\text{-quartz} \longrightarrow \beta\text{-quartz } 575^{\circ} \\ \beta\text{-quartz} \longrightarrow \alpha\text{-quartz } 570^{\circ} \\ \alpha\text{-tridymite} \longrightarrow \beta_1\text{-tridymite } 117^{\circ} \\ \beta_1\text{-tridymite} \longrightarrow \beta_2\text{-tridymite } 163^{\circ} \\ \text{Reversions on cooling not very sharp} \\ \alpha\text{-cristobalite} \longrightarrow \beta\text{-cristobalite } 274.6^{\circ} \text{ to } 219.7^{\circ}, \text{ depending upon previous heat-treatment} \\ \beta\text{-cristobalite} \longrightarrow \alpha\text{-cristobalite } 240.5^{\circ} \text{ to } 198.1^{\circ}, \text{ depending upon previous heat-treatment} \end{cases}$$

A study of the remarkable variations in the temperature of inversion of α - into β -cristobalite has led to the conclusion that this mineral is made up of two different molecular species of silica within the same crystal. Various other properties of the silica minerals seem to have considerable bearing upon theories of the structure of molecules and crystals. The nature of the radical differences existing between the two different types of inversion has been discussed in some detail.

The melting-point of cristobalite has been found to be close to 1625° . Quartz melts at least 155° lower.

The general stability relations are shown diagrammatically in figure 1.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, July, 1913.

ART. XXXV.—*Custerite: A New Contact Metamorphic Mineral*; by J. B. UMPLEBY, W. T. SCHALLER, and E. S. LARSEN.

Introduction.

THE new mineral here described is a hydrous fluosilicate of calcium which in thin section, in parallel light, resembles a pyroxene but with crossed nicols suggests albite. It was collected by one of the authors (J. B. Umpleby) in the fall of 1912, from a contact zone three and one-half miles southwest of Mackay, Custer County, Idaho. The zone is worked for copper, the ore occurring principally as irregular shoots in granite porphyry, well removed from its contact with the invaded Mississippian limestone. The ore minerals, principal among them chalcopyrite and its oxidation products, are intimately associated with garnet, diopside, magnetite, fluorite, and other contact minerals in bodies which are nearly coincident in extent with original limestone inclusions.* In some of these inclusions none of the original limestone remains, though locally its bedded structure is preserved in the garnet-diopside rock, but in others a core of unaltered blue limestone grades outward through pale-blue, partly recrystallized limestone into white marble and on into a zone made up largely of garnet, diopside, and magnetite. The new mineral was collected from between the garnet-diopside and marble zones which fringe one of these inclusions.

The name *custerite*, after the county in which it was found, is proposed for the mineral here described.

Occurrence and Genesis.

The mineral custerite was found about 200 feet within the margin of a great limestone inclusion which outcrops over an area of about 10,000 square feet on the first divide north of the Empire (formerly the White Knob) mine. It occurs intimately associated with magnetite and much less garnet and diopside. Hand specimens of usual size may be secured which show magnetite and custerite in about equal amount, and apparently of contemporaneous origin. The garnet and diopside occur in irregular scattered crystals many of which are euhedral. The relation of the custerite to these minerals is similar to the relation of calcite to them on the margins of garnet-diopside areas and suggests that they were developed

* This interpretation, which will be amplified in a report on the ore deposits by J. B. Umpleby, is at variance with that advanced by Kemp, J. F., and Gunther, O. G., *The White Knob Copper Deposits, Mackay, Idaho*: Am. Inst. Min. Eng., Bull. No. 14, pp. 301-328, 14 figs., March, 1907.

later than the custerite. This view seems to be supported by the occurrence of the mineral in the transition zone from garnet-diopside rock to marble and its apparent absence about the periphery of included limestone blocks where the metamorphic action was most intense. The thin sections and field relations therefore suggest that the custerite was formed in the outer part of the wave of metamorphism which passed from the magma into the limestone. It follows that in any given place there appears to have been a rather definite sequence of metamorphism from limestone to marble and thence through custerite into garnet-diopside-magnetite rock. If this sequence held throughout the deposit it is probable that the fluorine of the custerite is in part represented by the fluorite of the garnet-diopside rock. The field observations on the occurrence of custerite in the deposit, however, are so incomplete that further speculation as to its genesis might not even be suggestive.

Description of Mineral.

Custerite occurs in finely granular masses which may be easily mistaken for greenish marble, although the minute cleavage faces, which under the hand lens glisten in the sunlight, are roughly tabular in shape and chance ones show twinning lamellæ normal to the elongation. On weathered surfaces a chalky crust consisting chiefly of carbonate is not uncommon and for a distance of perhaps a millimeter beneath it the mineral is white and porcelain-like.

The physical properties of custerite, as determined from the hand specimen where individual crystals cannot be isolated, are as follows: Hardness, about 5; specific gravity 2.91 (corrected* for admixed diopside and magnetite); luster, greasy to vitreous; streak, white; color, pale greenish gray; tenacity, brittle; translucent.

A microscopic study of thin sections reveals an aggregate of irregular, diversely oriented interlocking grains, few of which exceed one millimeter in length by a width a little less. Most of the grains, however, are about one-half of a millimeter in diameter. The mineral has three cleavage directions which intersect at angles closely approaching 90 degrees. The cleavage in each of the three directions is so interrupted that it is impossible to measure accurately their angles of intersection. In two of the directions the cleavage is about equally prominent but in the other it is more nearly perfect. Polysynthetic twinning is beautifully developed parallel to this principal cleavage. The lamellæ are seldom wider than 0.01 millimeter and are commonly much narrower but are not uniformly dis-

* Value obtained = 2.96.

tributed, considerable areas of some of the crystals being untwinned. Sections cut normal to the obtuse bisectrix show the twin lamellæ which extinguish symmetrically at 6° – 7° from composition plane and the principal cleavage; those parallel to the plane of the optic axis are also normal to the twin lamellæ but the extinction is parallel. Sections cut normal to the acute bisectrix show no twin lamellæ. Here the cleavage intersects at angles of approximately 90° and the plane of extinction is diagonally across the squares, or at about 45° to each cleavage direction.

From the above relations of the optic properties to the cleavage directions and twinning it appears that the mineral possesses two cleavages, namely (110) and (001), with the twinning plane parallel to the latter. The conclusion that the mineral is monoclinic also seems warranted since the most careful measurements failed to show an inclined extinction of the lamellæ in one of the two principal sections normal to them. The accuracy of this observation was confirmed with the aid of the Federow stage on which a crystal was rotated in the plane of the twinning lamellæ and extinction angles were measured.

The positive acute bisectrix (Z) is nearly normal to the twinning lamellæ. The obtuse bisectrix (X) emerges from those sections cut normal to the twinning lamellæ which show an extinction ($Y \wedge a$) of 6° – 7° . This section is therefore normal to the crystallographic axis, b .

The optic axial angle measured with the Federow stage in lithium, sodium, and thalium light gave the following average results of readings on each axis by two observers:

Measurements of optic angles of custerite. Readings on Federow stage with section inclined $17\frac{1}{2}$ degrees.

	One axis	Other axis
Lithium light	32.25	34.7
Sodium "	31.85	34.65
Thalium "	31.25	35.

Correcting these readings, which were checked on another section, for the index of the glass and the tilting of the section, the following values are derived: $2V_u = 60.5^{\circ}$; $2V_{na} = 60.1^{\circ}$; $2V_{th} = 59.8^{\circ}$. Therefore, $2E = 105^{\circ}$. The dispersion of the optic axes as observed on the interference figure is rather strong and $\rho > \nu$. Crystals of custerite, as seen in thin section, are commonly almost equidimensional, though there seems to be a tendency toward elongation coincident with X .

The indices of refraction for custerite were determined by the oil-immersion method, the values below being fairly constant for different grains:

$$\begin{array}{ll}
 a = 1.586 \pm .005 & \gamma - a = .012 \\
 \beta = 1.589 \pm .005 & \gamma - \beta = .009 \\
 \gamma = 1.598 \pm .005 & \beta - a = .003
 \end{array}$$

The birefringence values derived by differences of refringence closely check with the following more accurate direct measurements on orientated sections respectively 0.06 and 0.1 of a millimeter thick :

$$\begin{array}{l}
 \gamma - a = .011 + \\
 \gamma - \beta = .009 + \\
 \beta - a = .004 -
 \end{array}$$

Custerite is characterized microscopically by its moderate index of refraction, low birefringence, polysynthetic twinning, maximum extinction angle of twin lamellæ of 6° – 7° , positive optical character, distinct dispersion of the optic axes with $\rho < \nu$, and three cleavages which intersect at high angles. There is no known mineral species from which it may not be readily distinguished optically. Its birefringence and twinning suggest albite, but its refringence is much higher. Its relief, lack of color, and cleavage in thin section might at first glance lead to its being mistaken for a colorless pyroxene, but its refringence and birefringence are lower, and its extinction angle is less than in all pyroxenes except ægirite. It resembles hillebrandite in index of refraction and birefringence, but that mineral is orthorhombic, optically negative, and occurs in fibrous forms. In relief and birefringence also it resembles eudialyte, which, however, is uniaxial and occurs in association with soda minerals.

It is believed that custerite is a mineral of rare occurrence, for its optical properties are so distinctive that it would scarcely have been overlooked. In the hand specimen, however, it is so unpromising in appearance that thin sections of it may never have been cut. The mineral should be looked for in fluorine-bearing contact zones, apparently in the border phases of the metamorphism.

Chemical Properties.

Pyrognostics, etc.—Heated gently in a closed tube, custerite turns a transitory yellow and phosphoresces with a golden yellow light. As seen in a darkened room, the color of the glow is like that of a deep colored golden beryl. On increasing the heat the phosphorescence is destroyed and water is given off. The mineral does not decrepitate. A white ring, due to the fluorine, is obtained by heating the mineral at a temperature sufficient to melt the glass tube. In the blowpipe flame, custerite fuses with difficulty, to an opaque white enamel.

The mineral is very readily decomposed by acids, gelatinous silica separating so quickly when the powdered mineral is

treated with HCl as to form a stiff coherent mass. The separated gelatinous silica floats around in an excess of acid, the solution itself not gelatinizing on further boiling. Custerite, therefore, does not "gelatinize" like natrolite.

Composition.—The chemical analysis showed that water, fluorine, silica, and lime were the essential constituents, the small amounts of iron and magnesium present being probably due to magnetite and diopside, respectively. Fairly pure, fresh material, suitable for analysis, was only available in portions of from one-fourth to three-fourth grams.

The analytical results obtained (by W. T. Schaller) are shown in the following table:

Analyses and Ratios of Custerite.

	1	2	Average	Ratios
SiO ₂ -----	32.13	32.20	32.17	.536
CaO -----	55.11	-----	55.11	.984
H ₂ O -----	5.53	5.06	5.30	.294
F -----	8.12	-----	8.12	.427
MgO -----	1.19	1.19	1.19	.030
Magnetite -----	0.85	1.14	1.00	---
			102.89	
			Excess of O due to F — 3.42	
			99.47	

These results were verified by a partial analysis (water not being determined) of a different, somewhat less pure, portion of the same specimen of custerite. The results obtained are: SiO₂, 33.46; CaO, 53.93; F, 7.29; MgO, 1.41; magnetite, 2.13. Alkalies were not determined on any of the samples because of paucity of material. Some of the whiter, chalky-looking material gave less water than the fresh material, several different samples yielding from 2 to 3 per cent H₂O instead of the 5 to 6 per cent given in the above analysis. Whether this represents an alteration of the custerite or a much impurer sample could not be determined on the scanty material available.

Interpretation of analysis.—The ratios derived from the above analytical figures can be interpreted either by considering that the small amount of magnesia belongs to the custerite or that it represents admixed diopside. These alternatives are shown in the table below:

Interpretation of Ratios of Average Custerite Analysis.

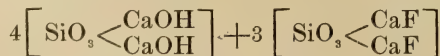
	Ratios	Combining CaO + MgO	Deducting diopside	Combining water and fluorine
SiO ₂	·536	2·00	2·00	2·00
CaO	·984	} 3·78	4·01	4·01
MgO	·030		---	---
H ₂ O	·294	1·10	1·24	2·14 H ₂ O or
F	·427	1·59	1·79	4·27 F

The formula derived for custerite is: $\text{Ca}_2\text{SiHFO}_4$ with some of the fluorine replaced by water (hydroxyl). The composition may also be expressed as a mixture of the two compounds: $2\text{SiO}_2 \cdot 4\text{CaO} \cdot 2\text{H}_2\text{O}$ and $2\text{SiO}_2 \cdot 4\text{CaO} \cdot 4\text{F}$, with the first one slightly in excess. The relation of the fluorine to water (hydroxyl) can be much better shown in the empirical formula, according to which the ratios reduce to $\text{Ca}_4\text{Si}_2\text{O}_6(\text{OH}, \text{F})_4$ with the ratio of hydroxyl (OH) to fluorine (F) as 2·48:1·79, or nearly 4:3.

No water was given off on heating custerite to 110°, indicating that the water is an inherent part of the mineral. The temperature at which the water does go off was not determined but the observation was repeatedly made that the phosphorescence phenomenon displayed itself and was destroyed by heat before the water was given off. Some powdered custerite, placed in a watchglass with several cubic centimeters of water, immediately gives a deep red color with a few drops of phenolphthaline. This reaction was described by Clarke,* and he has suggested that it is indicative of the presence of the univalent group — CaOH. As the ratio of OH to F is approximately 1:1, the formula of custerite may be structurally interpreted as a metasilicate, as follows:



The ratios of hydroxyl (OH) to fluorine (F) being not exactly 1:1 but more nearly 4:3, custerite may be more accurately considered as an isomorphous mixture of the following compounds, in the ratio indicated.



Relation to other minerals.—There are only three minerals known to which custerite is related in composition. These

* Clarke, F. W., Contributions to chemistry and mineralogy from the Laboratory of the United States Geological Survey: Bull. U. S. G. S., No. 167, p. 156, 1900.

are zeophyllite,* cuspidine† and hillebrandite.‡ The relationship in composition can be best shown by directly comparing their analyses.

Comparison of Composition of Custerite with Related Minerals.

	Custerite	Zeophyllite	Cuspidine		Hillebrandite
			Franklin Furnace	Vesuvius	
SiO ₂ -----	32·17	38·84	32·36	32·80	32·59
CaO -----	55·11	44·32	61·37	61·12	57·76
H ₂ O -----	5·30	8·98	---	none	9·36
F -----	8·12	8·23	9·05	9·88	---
Etc. -----	2·19	2·62	1·46	0·42	0·53
Deduct	102·89	102·99	104·24	104·22	100·24
O=F -----	—3·42	—3·47	—3·81	—3·98	---
	99·47	99·52	100·43	100·24	---

Zeophyllite is the only one of the three minerals which contains both water and fluorine. The proportions of silica and lime are different from those in custerite, though structurally its formula may be written in a somewhat similar way. The mineral is described as rhombohedral, the crystals being composed of a uniaxial center surrounded by a biaxial border. On being heated, the mineral becomes uniformly and permanently uniaxial. In its crystal form and physical and optical properties, there is no relation between zeophyllite and the other minerals chemically related to custerite. In its paragenesis it is also totally different from custerite, being a zeolite-like mineral found in basalt with natrolite, calcite, apophyllite, analcite, etc. A specimen of zeophyllite obtained through the kindness of Dr. Koechlin of the Vienna Hof-Museum was tested for its alkaline reaction and found to give only a very faint pink color with phenolphthaline.

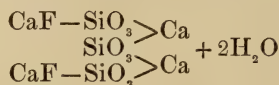
The dual optical character of zeophyllite suggests strongly that it is polymorphous. Possibly, the uniaxial compound is the zeolite-like mineral, bearing no relation to custerite, cuspi-

* Pelikan, A., Sitzber. Akad. Wien, vol. iii (1), p. 334, 1902. Cornu, F., Min. Petr. Mitt., vol. xxiv, p. 127, 1905.

† Palache, C., this Journal, vol. xxix, p. 185, 1910. Zambonini, F., Mineralogia Vesuviana, Att. Accad. Sci. Napoli, vol. xiv, No. 6, p. 273, 1910.

‡ Wright, F. E., this Journal (4), vol. xxvi, p. 551, 1908.

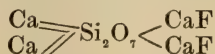
dene or hillebrandite. The biaxial compound, not found as such in nature, may possibly represent a compound similar in properties to custerite, cuspidine and hillebrandite. Its formula, $\text{Ca}_4\text{Si}_2\text{H}_4\text{F}_2\text{O}_{11}$, can be written as that of custerite plus one part of metasilicic acid, thus: $\text{Ca}_4\text{Si}_2\text{H}_2\text{F}_2\text{O}_8$ (custerite) + H_2SiO_3 , but what significance, if any, is to be attached to this fact is not known. The formula of zeophyllite can be interpreted structurally in a way analogous to that of custerite,



which would explain the fact that zeophyllite does not give a strong alkaline reaction with phenolphthaline but seems inconsistent with the fact that less than one per cent of the water is given off at 110° . Other structural interpretations are, of course, possible.

Cuspidine, found originally at Vesuvius, has recently been described from Franklin Furnace by Palache.* At Vesuvius cuspidine was found as well-developed crystals in druses associated with augite, hornblende, biotite, garnet, sarcolite, davynne, and calcite (derived from altered cuspidine). Granular aggregates—resembling a fine-grained diabase—of cuspidine with augite and biotite were also noted. Attention may also be called to the “cuspidine-like mineral” found† with green magnesium mica and white sodalite, and occurring in rhombic prisms, apparently different from cuspidine. The composition of this material is not known, though Zambonini‡ considers it identical with humite.

The density of the Franklin Furnace cuspidine is given as 2.965 – 2.989 and that of Vesuvius, as determined by Zambonini, as 2.962; average value 2.97. The formula derived by Zambonini, namely, $\text{Ca}_2(\text{CaF})_2\text{Si}_2\text{O}_7$, is in perfect accord with his own analysis and with Warren’s analysis of the Franklin Furnace material. It may be noted that the presence of only 0.57 per cent of water (not determined according to Warren’s analysis) in the Franklin Furnace mineral would suffice to bring the ratio of $[\text{F} + (\text{OH})] : \text{SiO}_2$ to 1.00 instead of 1.00 : 0.88 as calculated from his analysis. Structurally the formula of cuspidine can be interpreted as :



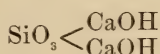
which does not show any direct relation to that of custerite.

* Loc. cit.

† Rath von G., Zs. Kryst., vol. viii, p. 45, 1884.

‡ Zambonini, Appendice alla Mineralogia Vesuviana; Att. Accad. Sci., Napoli, vol. xii, p. 44, 1912.

Hillebrandite is genetically similar to custerite, being one of the products of contact metamorphism of limestone adjacent to an igneous mass. A sample of hillebrandite kindly furnished for that purpose by Dr. F. E. Wright yielded 0.77 per cent of water at 110° and 9.64 per cent on ignition (calculated 9.45 per cent). The strong alkaline reaction with phenolphthaline, as described by Wright, was confirmed and suggests the presence of the CaOH group. On the basis of these results, the composition of hillebrandite can be readily interpreted as a meta-silicate with the following structural formula:



This formula is identical in type with that of custerite, and suggests at once that custerite is an isomorphous mixture of hillebrandite and a theoretic fluo-hillebrandite, in which all the hydroxyl is replaced by fluorine. This conception is a simple and rational one, but is opposed by other considerations:

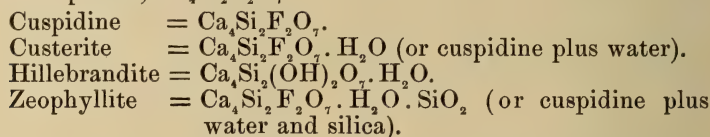
As cuspidine has been found at two widely separated localities, the inference may be justified that in the presence of much fluorine and little or no water, a mineral of the cuspidine formula, $3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{CaF}_2$, would always form instead of a fluo-hillebrandite with the formula $2\text{CaO} \cdot 2\text{SiO}_2 \cdot 2\text{CaF}_2$. In other words, fluo-hillebrandite seems to be unstable under the metamorphic conditions prevailing, judging, however, solely from the fact that at the only two localities where a calcium fluo-silicate occurs, a different type of compound (cuspidine) was formed. It seems likely, therefore, that, considering the isomorphous replacement of fluorine and hydroxyl, the isomorphous series of which hillebrandite is the hydroxyl end, consists of the two end members: $(\text{CaOH})_2\text{SiO}_3$ and $(\text{CaF})(\text{CaOH})\text{SiO}_3$ and not of the theoretic end members: $(\text{CaOH})_2\text{SiO}_3$ and $(\text{CaF})_2\text{SiO}_3$.

The symmetry of hillebrandite and custerite is apparently different, though some of the properties of hillebrandite could not be as definitely determined as those of custerite. The former mineral is fibrous, orthorhombic, whereas custerite is granular, monoclinic, with a close approach to orthorhombic symmetry, as evidenced by the nearly rectangular cleavages and low extinction angle. The custerite and hillebrandite compounds may both be dimorphous, with only the two non-isomorphous end members of the four possible compounds known.

The status of the relationship of these minerals, as far as can be judged by the available evidence, seems to be somewhat as is given below.

- Cuspidine — $\text{Ca}_4\text{Si}_2\text{F}_2\text{O}_7$.
 Theoretic fluo-hillebrandite — $\text{Ca}_4\text{Si}_2\text{F}_4\text{O}_6$ — unstable, non-existent.
 Custerite — $\text{Ca}_4\text{Si}_2\text{F}_2(\text{OH})_2\text{O}_6$, dimorphous: (1) orthorhombic form isomorphous with hillebrandite (not known) and (2) monoclinic.
 Hillebrandite — $\text{Ca}_4\text{Si}_2(\text{OH})_4\text{O}_6$, dimorphous: (1) monoclinic form isomorphous with custerite (not known) and (2) orthorhombic.
 Zeophyllite — $\text{Ca}_4\text{Si}_3\text{H}_4\text{F}_2\text{O}_{11}$, dimorphous, the known form not related to the above named minerals.

The close chemical relationship of these four minerals can be shown by writing their formulas so as to keep intact the common compound, $\text{Ca}_4\text{Si}_2\text{F}_2\text{O}_7$.



These relations suggest many things—the existence of a hydroxy-cuspidine, $\text{Ca}_4\text{Si}_2(\text{OH})_2\text{O}_7$; the derivability of custerite and zeophyllite (or a polymorphic form of the zeophyllite compound) from cuspidine by the actual addition of water and silica, etc.

The essential properties of the four minerals considered in the preceding paragraphs are briefly tabulated below for purposes of future reference.

Properties of Custerite and related minerals.

	Custerite.	Zeophyllite.	Cuspidine.	Hillebrandite.
Composition	$\text{Ca}_4\text{Si}_2\text{H}_2\text{F}_2\text{O}_8$	$\text{Ca}_4\text{Si}_3\text{H}_4\text{F}_2\text{O}_{11}$	$\text{Ca}_4\text{Si}_2\text{F}_2\text{O}_7$	$\text{Ca}_4\text{Si}_2\text{H}_4\text{O}_{10}$
Symmetry	Monoclinic	Rhombohedral	Monoclinic	Orthorhombic
Cleavage	Two, basal and prismatic	One, basal	One, basal	Prismatic (?)
Hardness	5–6	3	5–6	5–6
Density	2.91	2.75	2.97	2.69
Fusibility	Difficult	Very easy	Difficult	Difficult
Axial plane	Normal to basal cleavage	Normal to basal cleavage	{010}, normal to cleavage	Parallel to cleavage
Index γ	1.598	1.55	-----	1.612
Index β	1.589	-----	-----	-----
Index α	1.586	-----	-----	1.605
Birefringence	0.011	-----	-----	.007
2E	105°	0–27½°	110°	60–80°
Dispersion	Strong, $\rho > v$	$\rho < v$	Crossed, very distinct, $\rho > v$	$\rho < v$
Sign	Positive	Negative	-----	Negative
Extinction	6½°	-----	5°	0°
Twinning	Prominent, polysynthetic	-----	Tw. pl. (100)	-----
Elongation	-----	-----	-----	Z

ART. XXXVI.—*The Ordovician Outlier at Hyde Manor in Sudbury, Vermont* (second paper); by T. NELSON DALE.*

SINCE the publication of the former paper on this subject† further excavations and core drilling have thrown still more light on the areal and structural relations of the outlier. These later results, together with the former, are embodied in the map and section, fig. 1.

A series of holes (excav. 10, 11, 12) was dug across the sag in the surface west of the outlier, and the location of the boundary between the Cambrian schist mass and the Ordovician fossiliferous limestone west of it was fixed within five feet.

Other excavations (13, 14) showed that what had been taken for a minor fold in the main Ordovician mass was really the end of a limestone lens, 41–42 ft. long and up to 5 ft. thick, lying in the Cambrian schist and at one point with an inch or two of the schist actually overlying it. Whether this overlying schist got there by deposition or by "creep" after the solution of the limestone could not be ascertained. Then another limestone lens, about 7 feet long, was found a little west and south of the other. The age of these lenses is not determined; but they are probably contemporaneous with the schist and thus Cambrian.

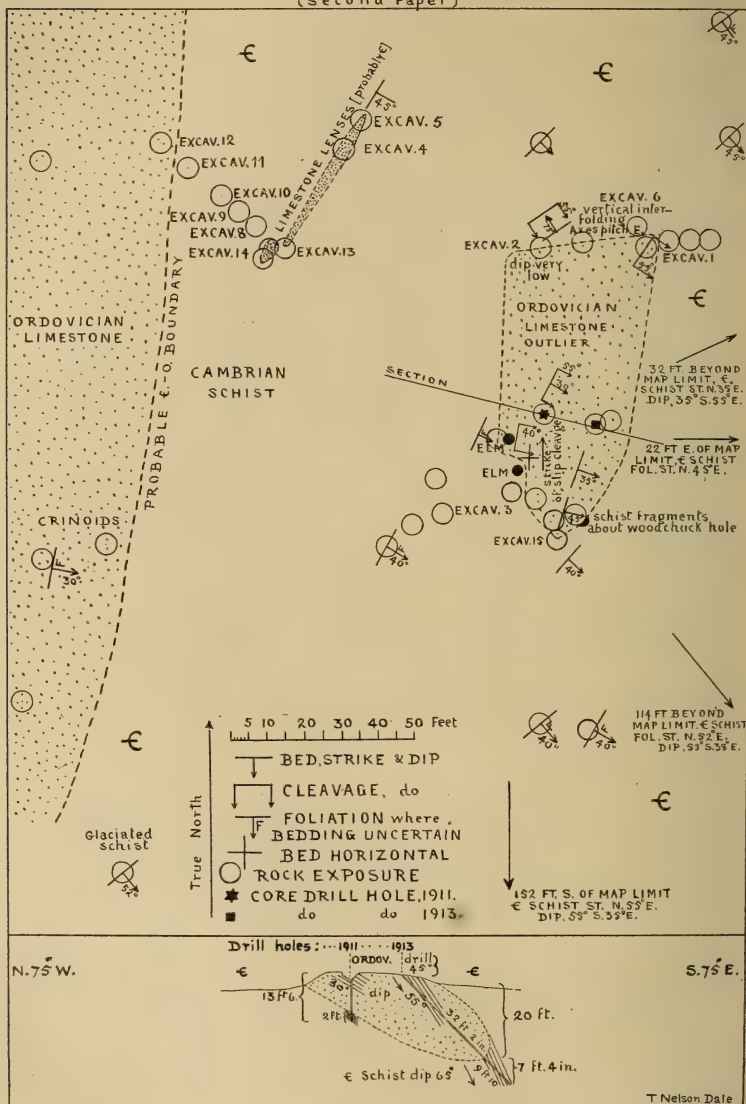
A small excavation at the southern apex of the outlier (excav. 15) shows that the limestone there pitches southward under the schist, the foliation of the schist which the microscope shows to be bedding, conforming to the limestone surface east of the point but running up against it on the west for at least a foot north. A woodchuck's burrow a little north of the apex has schist fragments about it brought up from next to the limestone.

Hand-specimens of the limestone from next to the drill hole of 1911 show two foliations, one dipping 30° about E.S.E., and the other, marked by sharply undulating and faulted calcite laminae, dipping 55° E.S.E. A thin section shows that the first of these foliations consists of undulating laminae of extremely fine particles (probably dolomite) alternating with laminae of coarser particles, probably calcite, containing here and there large calcite grains. The section also shows quartz grains distributed along this foliation. The second foliation, consisting of coarse calcite laminae, in sharp folds and faulted, breaks across the first and seems to be secondary. Both foliations are shown on the map at this point but with the same strike, which may not be exact. A thin section of the limestone at the southern apex shows that the foliation there which strikes N.

* Published by permission of the Director of the U. S. Geol. Survey.

† This Journal, vol. xxxiii, pp. 97–102, Feb. 1912.

FIG. 1.

THE ORDOVICIAN OUTLIER AT HYDE MANOR, SUDBURY, VT.
(Second Paper)

22° E. and dips 40° S. 78° E. is bedding. Therefore the strike of N. 10°–15° E. and dip of 45° S. 88° E., seven feet north of apex is very probably that of bedding also.

Strike observations were taken at all the Cambrian schist outcrops nearest to the outlier. In some the bedding was clearly shown by small lenses or beds of quartzite. In others the course of the bedding could not be fixed. All the data are shown on the map.

The conclusion is that Cambrian schist completely surrounds the Ordovician mass and has a bedding strike of N. 35°–60° E., generally N. 40°–50° E., that the limestone at excavation (2) rests unconformably on the schist, and that the bedding strike of the limestone is generally about 10 degrees west of that of the schist.

Finally, another drill core was obtained from a point, shown by black square on the map, 13 ft. 6 in. S. 75° E. of the first one, indicated by a star. The drilling was done with diamonds by the Vermont Marble Co., June 19–24, 1913. By inclining the drill at 45° eastward all possibility of mistake arising from its crossing an exceedingly overturned anticline was excluded. The results of this drilling are given below. The measurements are along the inclined drill.

9 feet.	----	Limestone.
4 "	----	Decomposed limestone and solution cave.
6 "	----	Limestone.
5 " 6 in.	----	Decomposed limestone and solution cave.
3 " 6 in.	----	Limestone.
3 "	----	Decomposed limestone and solution cave.
1 " 2 in.	----	Limestone.
4 "	----	Schist.
4 " 10 in.	----	Decomposed schist and joint space.
1 "	----	Schist.

42 ft.

The cores obtained measure :	Limestone.....	15 ft. 10 in.
	Schist.....	4 " 10·8 in.
		<hr/> 20 ft. 8·8 in.

One of the cores, broken into three parts, measured 30·5 inches, of which the upper two inches are Ordovician limestone and the rest, 28·5 in., is Cambrian schist. A thin section of the ordinary size could be furnished from this core which would show the rocks of both periods in contact. A photograph of this core will be shown in a future publication.

The bedding of the limestone, judging from the cores, dips about 55° eastward, and that of the schist about 65° eastward.

The general results of the last drilling are shown in the section on fig. 1.

In view of the fact that the schist dips under the Ordovician on the west side of the outlier at the outcrop next to the northern elm, and overlies it on the east side at excavation (1), and again underlies it in the western half of the outlier, 11 ft. 6 in. below the surface, as determined by the drilling of 1911, and, finally, also underlies the Ordovician in the eastern half, 20 ft. vertically below the surface at the eastern edge, as determined by the drilling of 1913, the synclinal character of the outlier, as shown in the former article, is still more completely demonstrated. As the schist overlies the limestone on the east side at excav. (1) with an eastward dip of 35° – 45° , the presence of schist below the limestone lower down on the east side, as shown by the core drilling of 1913, is just what would not be expected under the hypothesis of an overturned anticlinal structure. Only a very arbitrarily distorted diagram, contrary to the entire habit of the rocks of the Taconic region, could make the outlier into an anticline. But the syncline proves to be much more elongated along its axial plane than shown in fig. 2 (H) of the first paper, its deepest part on the line of section being 24 feet vertically below the highest part of the outlier.

The unconformity between the Cambrian and Ordovician beds, already shown by specimens obtained at the contact at excavation (2),* is again shown in the cores by the difference in bedding dip.

The interpretation of the structure as consisting of Cambrian schist thrust over Ordovician limestone and both folded into an overturned anticline, with the subsequent erosion of the Cambrian to form a "Fenster," is shut out by all the laws of probability applied to the conjoint evidence of the outcrops, the excavations, the cores, thin sections, and the habit of the region.

The correctness of the conclusions of the first paper as to the general significance of the outlier† is thus made still more probable.

The interfolding of the limestone at the northeast corner, excavation (6), and the pitch of the limestone under the schist at excavation (15), taken together, indicate transverse folding quite typical of the Taconic region.

The cores will be preserved at the National Museum.

Pittsfield, Mass., July 11, 1913.

* Op. cit., this Journal, fig. 2 (B).

† Ibid., pp. 101, 102.

ART. XXXVII.—*On the Preparation of Tellurous Acid and Copper Ammonium Tellurite*; by G. O. OBERHELMAN and P. E. BROWNING.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cexlix.]

OCCASION having arisen to prepare some tellurous acid from residues from the electrolytic refining of copper,* residues containing a high percentage of tellurous oxide together with small amounts of silica, copper, selenium, and several other impurities, it was determined to try the effect of the solvent action of ammonium hydroxide, followed by the precipitation of the tellurous acid from the ammoniacal solution by acetic acid. This procedure, employed on another occasion for the removal of selenium,† proved satisfactory for the removal of the greater part of the silica, and of those bases which are insoluble in ammonium hydroxide. By dissolving the tellurous acid thus obtained in sodium hydroxide and precipitating the tellurous acid again by acetic acid, copper and many other metals whose hydroxides are insoluble in sodium hydroxide were also removed.

If the precipitation of the tellurous acid by acetic acid is brought about without warming the solution, and the product is dried without heating, the tellurous acid obtained is readily soluble in the alkali hydroxides. If, however, the precipitation takes place in hot solution and the precipitate is dried by application of heat, the product tends to be quite insoluble in the alkali hydroxides.

After the first treatment of the residues with ammonia in this extraction process, it was observed that a purple crystalline salt separated from the alkaline solution on standing. The color suggested a copper compound, and after the removal of this salt by filtration, the filtrate proved to be practically free from copper. It was found that a salt similar in appearance could be produced by allowing an ammoniacal solution of tellurous acid containing some copper salt to evaporate over sulphuric acid, and in the presence of soda-lime. The depth of color varied with the concentration of the copper solution from a reddish purple through pink to nearly white. It was found that a salt which appeared to be identical with the compound just mentioned, could be produced by adding slowly, with constant stirring, acetic acid to an ammoniacal solution of tellurous oxide and copper chloride. The precipitate thus obtained proved to be slightly soluble in water but insoluble in acetic acid and in 50 per cent alcohol. A sample of this compound prepared in the manner

*Furnished through the kindness of the Baltimore Copper Co.

† Browning and Flint, this Journal (4), xxviii, 112, 1909.

just described, which from its intensity of color was considered to contain the maximum amount of copper, gave the following analysis:

TeO ₂	83.84
CuO	4.63
NH ₃	5.22
H ₂ O	6.10
	<hr/>
	99.79

The TeO₂ was determined by the permanganate method. Copper was estimated colorimetrically by comparing in Nessler tubes ammoniacal copper solutions of known strength with weighed amounts of the compound dissolved in acid and made ammoniacal. This method was found to be accurate to 2/10ths of a mg. The ammonia was determined by distillation from an alkaline solution into standard acid. The water could not be determined by difference on ignition, owing to a slight reduction of the tellurium. So the compound was heated at 140°, and the residual ammonia was determined after weighing. From the weights of the total ammonia and of the residual ammonia at 140°, together with the total loss on heating at 140°, the weight of the water was determined. The loss of ammonia which resulted from heating at 140° proved to be about constant and amounted to a third of the total ammonia. The color of the substance changed on heating at 140° from reddish-purple to blue.

It was thought that compounds of a similar nature containing bases other than copper might be formed in a similar manner. Nickel, cobalt, zinc, cadmium, and silver were tried but with no success. Silver gave a yellow precipitate, but this proved to be the ordinary silver tellurite.

ART. XXXVIII.—*Determination of Water of Crystallization in Sulphates*; by S. B. KUZIRIAN.[Contributions from the Kent Chemical Laboratory of Yale Univ.—*cel.*]

CERTAIN substances, e. g. chlorides of barium and calcium, sulphates of sodium, potassium, barium, etc., are completely dehydrated at moderately high temperatures, leaving a definite and weighable compound. Under such conditions, when the substances do not lose anything but water, at a definite temperature, the determination of water of crystallization can be made with great ease.

Certain other substances, like the minerals, talc, topaz, chondrodite, staurolite, do not lose all of the water of crystallization by simple ignition at moderate temperatures. The high heat of the blast lamp is in such cases applied for the complete removal of water. This latter step often gives rise to complications, when the material to be blasted changes weight otherwise than by loss of water, e. g. by loss of carbon dioxide, fluorine, chlorine, or by accession of oxygen, as when a ferrous compound is ignited in air.

Some other crystalline substances like sulphates and alums of aluminum and chromium are decomposed with loss of material other than water, at temperatures obtainable with an ordinary good-sized Bunsen burner, thus preventing a correct determination of their crystalline water.

Various modifications in treatment have been suggested to avoid complication in water determinations. For instance, in the case of minerals, talc, topaz, etc., fusion with pure and dry sodium carbonate* will expel the water which may be absorbed in sulphuric acid and weighed.

Fusion of such silicates, very finely pulverized, with anhydrous powdered borax, is another method suggested by Jannasch,† for the same object. If the silicates are found to contain fluorine, then a retaining layer of granular lead chromate or a previously fused and powdered lead oxide is used in the ignition tube. This process is found objectionable by W. H. Hillebrand‡ for the reason that silicates on fine grinding lose some water.

Magnesia§ is another substance mentioned in connection with determination of crystalline water in decomposable compounds

* Bulletin 422, United States Geol. Survey, Hillebrand, p. 79.

† Praktischer Leitfaden der Gewichtsanalyse, Leipzig (1897, 2d ed.).

‡ Bulletin 422, United States Geol. Survey, Hillebrand, p. 83.

§ F. Stolba, Zeitschr. f. analyt. Chem, vii, 23.

like silico-fluorides. Under definite conditions, this flux seems to give satisfactory results, a correction being necessary when the separated metallic oxide, e. g. ferrous oxide, takes up atmospheric oxygen. In the case of decomposable sulphates, however, no attempt has been made to determine their water of crystallization, while retaining all of the acidic oxide.

In the investigation of the action of sodium paratungstate upon some salts, containing a volatile acid radical, both in presence and absence of superheated steam, described in previous papers,* it has been shown that this acidic salt is able to expel the acidic oxides of carbonates, nitrates, chlorides, chlorates, etc., completely and with great ease. But sulphates which are stable on simple ignition, for example, the sulphates of sodium, potassium, barium and even calcium and manganese, do not lose appreciably their sulphur trioxide, either in absence or in presence of superheated steam on fusion with the paratungstate. For example, 0.2 grm. of sodium sulphate on fusion with the paratungstate did not lose in weight at all. The same amount of manganous sulphate when fused with the same flux lost only 0.0010 grm. of sulphur trioxide. Calcium sulphate on similar treatment lost only 0.0002 grm. and further heating did not occasion further loss. The explanation is that the basic sodium oxide of the sodium paratungstate combines with volatile sulphur trioxide of the sulphates to form the non-volatile sodium sulphate. The presence of a considerable excess of the acidic tungsten trioxide apparently does not influence the reaction.

The following may serve as a typical representation of the reaction :



Since sodium paratungstate does not expel the volatile sulphur trioxide from sulphates, it should be capable of serving a useful purpose as a flux in the expulsion of the water of crystallization of sulphates ordinarily decomposable by heat; and any sodium tungstate containing less of this acidic oxide should be similarly serviceable. In the preliminary investigation of this application of the sodium tungstates a nearly neutral sodium tungstate was prepared,† and a portion of the dry material was weighed and placed in a platinum crucible, a weighed portion of a decomposable sulphate—viz., crystalline copper

* This Journal (4), xxxi, 497; xxxvi, 301, 305.

† In order to purify the commercial material, which ordinarily contains sodium carbonate, it was fused in a large platinum dish over the blast, and pure tungstic trioxide was added until carbon dioxide ceased to bubble out.

sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$)—was mixed well with the tungstate, and the covered crucible heated with a very low flame of a Bunsen burner waving under it. After driving off most of the water, the crucible was heated to low redness and the mixture fused, cooled and weighed. The loss apparently corresponded exactly to the theoretical loss of water in $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$. The fusion was repeated several times and weighed over again, but no further loss in weight was found. So it appears that, while crystalline copper sulphate loses some of its sulphur trioxide when heated by itself at the temperature which is necessary for its complete dehydration, no loss of the acidic oxide occurs in presence of sufficient amount of neutral sodium tungstate when the mixture is heated over a Bunsen flame to dull red heat. It is possible to keep the mixture in quiet fusion for fifteen to twenty minutes without losing any sulphur trioxide. Sodium tungstate thus serves excellently to retain the sulphur trioxide at a temperature sufficiently high to dehydrate the sulphate completely.

To determine the water of crystallization in sulphates by weighing the water evolved, as well as by loss on ignition, the following procedure was tried. A hard glass ignition tube, about 15 inches long and $1\frac{1}{2}$ inches in diameter, was placed upon a small furnace; each end was fitted with a perforated (one hole) rubber stopper soaked in hot paraffine for a moment and wiped carefully; and one end of it was connected with a large air-drying apparatus while the other end was joined to a sulphuric acid weighing tube. The sulphuric acid tube was connected to a calcium chloride drying tube to prevent the entrance of any moisture into the weighing tube from outside, and the calcium chloride tube was connected to an aspirator. The ignition tube was thoroughly dried by heating it for at least forty-five minutes and passing a rapid current of dry air with the aid of the aspirator. The efficiency of the apparatus was evident from the fact that when, after such drying, the sulphuric acid weighing tube was connected with the ignition tube and a blank test made, by running the apparatus for one hour, a gain of only 0.0003 gr. in the weight of the weighing tube resulted, for which a correction was applied in the subsequent work. After having the apparatus thus in readiness, exactly half a gram of the sulphate was mixed well with three grams of sodium tungstate in a porcelain boat, ignited and weighed previously. The boat and its contents, weighed together, were introduced into the ignition tube. The ignition was started at first very gently by passing a current of hot dry air over the boat, at a rate of 3 bubbles a second, for a period of fifteen minutes. The temperature was carefully and gradu-

ally increased, until the mixture went into clear fusion. By waving a Bunsen flame around the ignition tube, and short delivery tubes, the condensed moisture was volatilized. After the apparent disappearance of all moisture, the remaining traces of it were forced into the sulphuric acid weighing tubes by a more rapid current of dry air, while continuing the heating of the ignition and delivery tubes for at least twenty minutes. After this period the heating was stopped, while a rapid current of dry air was passed for about ten minutes. The weighing tube was disconnected, stoppered with the glass plugs used as stoppers in the first weighing, brought as nearly as possible to the original temperature (by setting it aside for a few moments), wiped around with a filter paper, and weighed. The gain in weight of the weighing tube was recorded. After disconnecting the weighing tube from the ignition tube, the delivery tube leading into the ignition tube was plugged carefully, to avoid any moisture. The boat was taken out while rather hot, cooled in a desiccator over sulphuric acid and weighed, and the loss in weight was recorded. It was found that if the procedure was carried out with the utmost care, observing all the precautions, the loss in weight of the porcelain boat, within experimental error, corresponded to the gain in weight of the sulphuric acid tube, and this corresponded closely to the theory for water in the crystallized sulphates. Repeated fusions of the contents of the boat did not occasion any further loss in weight, thus proving that under the conditions there is no loss of sulphur trioxide.

The sulphuric acid weighing tube used was a side-neck U-tube filled with glass beads and the ends of the large tube were sealed. The rubber connectors were air tight so that the weighing tubes would not gain in weight over night. It is desirable that the sulphuric acid in the drying apparatus and in the weighing tube should have the same absorbing power; for this reason the sulphuric acid in the weighing tube was changed after every four determinations.

The determination of the water of crystallization in copper sulphate, and in other sulphates, was carried out under the conditions cited above, with special precaution to avoid loss by decrepitation of the salt while yielding its water. After mixing the sulphate well with sodium tungstate, another portion of the flux was put upon the surface of the mixture to form a trap, and thus avoid mechanical loss, and the mixture was heated with utmost care for a long time at a temperature not exceeding 70° centigrade. Following are some of the results obtained with various sulphates :

TABLE I.

Determination of water of crystallization in various sulphates.

Sulphate taken gram.	Dried sodium tungstate taken gram.	Loss of the porcelain boat after ignition gram.	Gain of sulphuric acid weighing tube gram.	Difference.
Copper Sulphate.				
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$.				
0.2000	4	0.0707	0.0701	-0.0006
0.2000	4	0.0715	0.0712	-0.0003
Aluminum Sulphate ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$).				
$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$.				
0.2000	4	0.0897	0.0913	+0.0016
0.2000	4	0.0900	0.0894	-0.0006
0.2000	4	0.0907	0.0915	+0.0008
0.2000	4	0.0925	0.0935	+0.0010
Nickel Sulphate ($\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$).				
$\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$.				
0.2000	3	0.0822	0.0831	+0.0009
0.2000	3	0.0832	0.0833	+0.0001
0.2000	3	0.0826	0.0825	+0.0001
Chrome Alum ($\text{K}_2\text{SO}_4 \cdot \text{Cr}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$).				
$\text{K}_2\text{SO}_4 \cdot \text{Cr}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$.				
0.2000	4	0.0807	0.0800	-0.0007
0.2000	4	0.0755	0.0755	0.0000
0.2000	4	0.0780	0.0794	+0.0014
Potassium Alum ($\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$).				
$\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$.				
0.2000	3	0.0915	0.0923	+0.0008
0.2000	2	0.0911	0.0929	+0.0018
0.2000	3	0.0910	0.0915	+0.0015
0.2000	3	0.0915	0.0928	+0.0013

From the results detailed in the above table, it is evident that there is no loss other than water during the fusion. Even from aluminum and chromium sulphates which lose their acidic oxide on simple ignition, no sulphur trioxide is volatilized in the presence of sodium tungstate. The water of crystallization of these sulphates may, therefore, be determined in a remarkably short time and with great accuracy with the use of this flux, and the advantage to be derived is obvious and needs no particular comment.

In the case of an acidic sulphate the entire amount of the acidic oxide will be retained by the tungstate, and the water of constitution as well as the water of crystallization will be evolved.

The extension of the use of this flux to the estimation of water in salts other than sulphates is, for lack of time, left to some future date.

ART. XXXIX.—*The Paleozoic Section in Northern Utah;*
by G. B. RICHARDSON.*

Introduction.—One of the most complete Paleozoic sections known in the entire Cordilleran region is exposed in the vicinity of Bear Lake, northern Utah. This section embraces more than 14,000 feet of strata and includes seven Cambrian, three Ordovician, one Silurian, two Devonian and four Carboniferous formations. The entire sequence is well exposed in the Randolph quadrangle, which was studied in the summer of 1912 by the writer, assisted by Paul V. Roundy, to whom he is indebted for measuring a number of sections and collecting many of the fossils. G. H. Girty visited the party during the progress of field work and, in addition to identifying the Carboniferous fossils, was of great help in making collections. The writer also acknowledges his indebtedness to Messrs. E. O. Ulrich, E. M. Kindle, L. D. Burling and Edwin Kirk for examining the fossils.

The table on page 407 summarizes the Paleozoic rocks of northern Utah.

Cambrian.

The Cambrian section in the Randolph quadrangle is essentially that described by Walcott† as occurring in Blacksmith Fork, Utah, and in the vicinity of Liberty, Idaho, and need not be described here. This section is finely exposed on the eastern flank of Bear River Range west of Garden City, where the thicknesses recorded in the table were measured. There the formations named by Walcott were recognized by their lithology, stratigraphic position and fossils, which latter were examined by L. D. Burling, who assisted Walcott in the study of the type section. In the preparation of the geologic map of the Randolph quadrangle it was found desirable to differentiate the Hodges shale member at the base of the Bloomington formation and the Worm Creek quartzite member at the base of the St. Charles limestone.

The Hodges shale member of the Bloomington formation is a persistent zone of drab clay shale about 350 feet thick, occurring at the base of the formation. It lies apparently conformably on the massive Blacksmith limestone, and is overlain by thin-bedded limestone of the Bloomington formation. The name is derived from Hodges Creek, which crosses the shale and enters Bear Lake $1\frac{1}{2}$ miles south of Garden City.

* Published by permission of the Director, U. S. Geological Survey.

† Walcott, C. D.: *Cambrian Geology and Paleontology*, Smithsonian Miscellaneous Collections, vol. liii, pp. 5-9 and 190-200, 1908; also Mon. U. S. Geol. Survey, No. 51, pp. 148-153, 1912.

Paleozoic formations in Northern Utah.

System.	Series or fauna.	Formation.	Approximate thickness in feet.	General character.
Carboniferous	Permian ?	Phosphoria formation	400	Chert and siliceous limestone overlying shale, thin limestone and oolitic phosphate rock.
	Pennsylvanian	Wells formation	less than 300 to 600	Massive gray quartzite overlain and underlain by thinner bedded quartzite and limestone.
	Mississippian	Brazer limestone	800 to 1400	Massive to thin-bedded light gray siliceous limestone and sandstone.
		Madison limestone	600 to 1600	Medium to thin-bedded dark limestone rich in fossils.
Devonian	Upper	Threeforks limestone	200	Soft reddish rocks poorly exposed in Randolph quadrangle.
	Middle and Lower	Jefferson dolomite	1200	Massive, fine-grained dark dolomite, weathers a characteristic brown tint.
Silurian		Laketown dolomite	1000	Massive light gray dolomite.
Ordovician	Richmond fauna	Fish Haven dolomite	500	Medium-bedded bluish dolomite.
	Chazy ? fauna	Swan Peak quartzite	500	Fine textured gray quartzite.
	Beekmantown fauna	Garden City limestone	1000	Thick- and thin-bedded gray limestone.
Cambrian	Upper	St. Charles limestone	1300 to less than 500	Massive gray limestone with 300 ft. of massive gray quartzite at the base.
		Worm Creek quartzite member		
	Middle	Nounan limestone	950	Massive to medium-bedded gray limestone.
		Bloomington formation	1250	Thin-bedded limestone and shale, Hodges shale member at the base.
		Hodges shale member		
		Blacksmith limestone	700	Massive fine-grained gray to bluish limestone.
		Ute limestone	480 to 585	Thin limestone, interbedded with shale.
		Spence shale member		
		Langston limestone	375	Massive crystalline blue to gray limestone.
	Middle and Lower	Brigham quartzite	1600 +	Massive fine-grained gray quartzite locally conglomerate.
		Base not exposed		

The Worm Creek quartzite member of the St. Charles limestone is a massive gray quartzite occurring at the base of the formation. It is of variable thickness, having a maximum of 300 feet in the Randolph quadrangle. The Worm Creek quartzite directly overlies the Nounan limestone and is succeeded by the massive gray fossiliferous Upper Cambrian limestone which forms the bulk of the St. Charles limestone. The name is derived from Worm Creek, in the Bear River Range, 10 miles north of the Randolph quadrangle.

Ordovician.

Overlying this great thickness of Cambrian rocks the Ordovician system likewise is well developed in the Bear River Range, notably adjacent to the Idaho-Utah state boundary, where it is represented by a continuous exposure of 2,000 feet of strata. These beds are separated into the following formations: the Garden City limestone containing a Beekmantown fauna, the Swan Peak quartzite containing a Chazy ? fauna, and the Fish Haven limestone characterized by a Richmond fauna. Although the succession is apparently conformable, there is nevertheless evidence of erosional unconformity at the base of the lowermost and uppermost Ordovician formations. These unconformities are inferred from the facts that the Garden City limestone and the Fish Haven dolomite, respectively, rest on such different horizons in different parts of the Randolph quadrangle that considerable erosion apparently preceded their deposition. Details will be given in the Randolph folio.

Garden City Limestone.

The Garden City limestone, named from Garden City Canyon, a tributary of Bear Lake, consists of a succession of thick and thin bedded gray limestone approximately 1,000 feet thick. A characteristic feature is the presence throughout the formation of a conglomerate or breccia consisting of elongated bits of limestone up to 2 or 3 inches in length, irregularly imbedded in a matrix of similar composition.

The following fossils, identified by Edwin Kirk of the U. S. Geological Survey, were obtained from the Garden City limestone in the Bear River Range, Randolph quadrangle, at the horizons indicated:

From the eastern flank of Bear River Range 4 miles northwest of Garden City, Utah—

From the base of the Garden City limestone, within 25 feet of St. Charles limestone:

Dalmanella sp.
Syntrophia near *calcifera*
Billings

Raphistoma acuta H. & W.
Hormotoma sp.
Eccyliopterus sp.

From 187 feet above the base of the Garden City limestone :

Lingula sp. *Asaphoid*

From 337 feet above the base of the Garden City limestone :

Streptorhynchus minor *Asaphus* ?

Walcott

A new genus of trilobites allied to Bumastus

From 375 feet above the base of the Garden City limestone :

Dalmanella sp. *Asaphus* sp.

Raphistoma sp. *Ribeiria* sp.

Maclurea subannulata Walcott

From 675 feet above the base of the Garden City limestone :

Strophomena fontinalis White *Maclurea subannulata* Walcott

Dalmanella pogonipensis *Hormotoma* sp.

H. and W. *Eccyliopterus* sp.

Streptorhynchus minor Walcott *Asaphus* ? *curiosus* Billings

Eostrophomena n. sp. *Asaphus* sp.

Raphistoma ? near *trohiscus* *Bathyrurus* sp.

Meek *Receptaculites* sp.

Raphistoma acuta H. and W.

From the top of the Garden City limestone :

Dalmanella pogonipensis *Hormotoma* sp.

H. and W. *Echinoencrinus* ? sp.

Strophomena fontinalis White *Leperditella* sp.

The fauna of the Garden City limestone is represented in part by that of certain portions of the Pogonip limestone of the Eureka district, Nevada. It is equivalent to the Beekmantown fauna of the East.

Swan Peak Quartzite.

The Swan Peak quartzite, named from Swan Peak in the Bear River Range, Utah, $1\frac{1}{2}$ miles south of the Idaho boundary, is a fine-textured massive to thin-bedded white to gray quartzite about 500 feet thick which lies apparently conformably on the Garden City limestone. The following fossils, identified by Edwin Kirk, were obtained from this quartzite in the NE $\frac{1}{4}$ sec. 9, T. 14 N., R. 4 E., *Orthis* n. sp. near *tricenaria* Conrad, *Eccyliomphalus* sp., *Endoceras* sp. *Ampyx*?, *Symphysurus*? *golfussi* Walcott, *Bathyrurus congeneris* Walcott, *Leperditia* sp., *Leperditella* sp. This fauna, which is related to that occurring in the lower part of the Simpson formation in Oklahoma, is referred tentatively to the Chazy by Ulrich and Kirk.

Fish Haven Dolomite.

In the Bear River Range near the Utah-Idaho boundary the Swan Peak quartzite is immediately overlain by the Fish

Haven dolomite, which is a fine-textured medium-bedded dark gray to blue-black, locally cherty, dolomite about 500 feet thick containing a Richmond fauna. The name is derived from Fish Haven Creek, which enters Bear Lake, Idaho, about 2 miles north of the Utah State Line. A sample from the head of Fish Haven Creek, analyzed by Walter C. Wheeler of the U. S. Geological Survey, showed 21.35 per cent of magnesia.

The following fossils, identified by Edwin Kirk, were obtained by R. W. Richards in the Fish Haven dolomite near the crest of the Bear River Range at the head of Fish Haven Creek in the Montpelier quadrangle, Idaho, immediately north of the Randolph quadrangle: *Calapoecia* cf. *Canadensis* Bill., *Streptelasma* sp., *Halysites catenulatus* var. *gracilis* Hall, *Rhynchotrema* cf. *capax* Conrad, *Columnaria thomii* Hall. This represents a widespread western Richmond fauna.

SILURIAN.

Laketown Dolomite.

The Laketown dolomite, named from Laketown Canyon 4 miles southeast of Laketown in the Randolph quadrangle, is a massive light gray to whitish dolomite, containing lenses of calcareous sandstone, having a thickness of approximately 1000 feet. An analysis of a sample from SE $\frac{1}{4}$ sec. 17, T. 12 N., R. 6 E. showed 21.38 per cent MgO. In the Montpelier quadrangle, Idaho, R. W. Richards reports a few feet of the Laketown dolomite lying above the Fish Haven dolomite apparently conformably, but the most complete section of this formation is in Laketown Canyon. There, however, because of the scarcity of fossils, the lower boundary and consequently the thickness of the Laketown dolomite has not yet been determined. Fossils in general are rare in the Laketown dolomite although locally there occur considerable quantities of a poorly preserved *Pentamerus* cf. *oblongus* Sow. Specific identification is impossible, but they clearly point to the Silurian age of the containing beds. A similar fauna was reported by Kindle* from Green Canyon east of Cache Valley. Some poorly preserved corals, identified provisionally as *Halysites catenulatus*? Linn., *Favosites* sp. and *Cyathophyllum*? sp., were found in the lower part of the dolomite in Laketown Canyon, but it is doubtful whether these fossils, here tentatively referred to the Silurian, may not be Richmond. It is proposed to restrict the name Laketown dolomite to beds of Silurian age.

* Kindle, E. M.: The fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region. Bull. of American Paleontology, No. 20, p. 17, 1908.

DEVONIAN.

Jefferson dolomite.

The Jefferson limestone of Lower and Middle Devonian age, which has a widespread distribution in the northern Rocky Mountain region, is well developed in the Randolph quadrangle, where, however, the name dolomite is applied instead of limestone because of the magnesian content. A sample from Laketown Canyon showed the presence of 19.16 per cent MgO. In the area here considered the Jefferson consists chiefly of massive fine-grained dark-colored dolomite, weathering a characteristic brownish tint, but in places, as in Laketown canyon, the lower strata are thin-bedded. The Jefferson is about 1200 feet thick, and overlies the Laketown dolomite apparently conformably. Fossils are not abundant although two collections were obtained in Laketown Canyon, one from near the top of the dolomite and the other from near its base. Both lots were identified by E. M. Kindle.

Fossils from Jefferson dolomite, Randolph quadrangle.

From East Fork of Laketown Canyon, SE $\frac{1}{4}$ sec. 17, T. 12 N., R. 6 E., about 150 feet above the base of the formation :

Productella sp.

Aviculopecten? sp.

Spirifer englemanni

Fish bone fragment.

Nuculites sp.

From East Fork of Laketown Canyon, W $\frac{1}{2}$ sec. 17, T. 12 N., R. 6 E., from several beds between 200 and 500 feet below the top of the formation.

Aulopora sp.

Zaphrentis sp.

Favosites cf. *limitaris*

Dr. Kindle reports that "the coral listed here as *Favosites* cf. *limitaris* is one of the characteristic and widely distributed fossils of the Jefferson limestone of the northern Rocky Mountain region. One of the species of the preceding faunule, *Spirifer englemanni*, is also a characteristic fossil of this formation."

Threeforks limestone.

At the type locality, Threeforks, Montana, the Threeforks limestone, there the Threeforks shale, lies conformably between the Madison and Jefferson limestones. But although the Threeforks has not been recognized over so wide an area as have the immediately overlying and underlying formations, in the Randolph quadrangle all three formations are present, the Threeforks being definitely recognized by fossil evidence.

The Threeforks limestone is a soft formation lying between harder ones and in the area here considered usually occupies

talus slopes or debris-covered lowlands so that nowhere was a complete exposure of the formation found and only thin beds of impure reddish-colored limestone were observed, the stratigraphic interval between the underlying Jefferson and overlying Madison limestone being about 200 feet. This soft reddish zone lying between well marked massive limestone is an excellent horizon marker.

In the Randolph quadrangle the Threeforks limestone outcrops in two distinct areas in Laketown Canyon and in the Crawford Mountains but fossils were found in it only in the Crawford Mountains, where the following lot, identified by E. M. Kindle, was obtained in S $\frac{1}{2}$ sec. 29, T. 11 N., R. 8 E.

<i>Productella coloradensis</i>	<i>Syringothyris</i> cf. <i>carteri</i>
<i>Camartoechia</i> cf. <i>contracta</i>	<i>Spirifer whitneyi</i> var. <i>animasensis</i>
<i>Schizophoria striatula</i> var. <i>australis</i>	<i>Cleiothyridina</i> sp. undet.
<i>Spirifer notabilis</i>	

Dr. Kindle states that this fauna is of Upper Devonian age and includes elements both of the Ouray limestone and Threeforks shale fauna.

It may be observed in passing that reddish beds referred to by Blackwelder as constituting a "non-marine member in the Mississippian limestone"* exposed around the sources of the south fork of Ogden River, Utah, and thought by him to be of continental origin, may prove to be the marine Threeforks.

Carboniferous.

The Carboniferous rocks of the area under consideration outcrop in the Crawford Mountains east of the town of Randolph, where the entire local section is well exposed.

MISSISSIPPIAN SERIES.

Madison limestone.

The Threeforks limestone is apparently conformably overlain by the well known Madison limestone, which here is a medium to thin-bedded dark limestone of variable thickness ranging from about 600 to 1600 feet thick. It is abundantly fossiliferous. The following small selected list was identified, and in part collected, by G. H. Girty:

Fossils from Madison limestone, Randolph quadrangle:

<i>Menophyllum excavatum</i>	<i>P. gallatinensis</i>
<i>Leptaena analoga</i>	<i>Camartoechia herrickana</i>
<i>Schuchertella chemungensis</i>	<i>Spirifer centronatus</i>
<i>Productella concentrica</i>	<i>Reticularia Cooperensis</i>
<i>P. arcuata</i>	<i>Syringothyris carteri</i>
<i>Productus levicosta</i>	<i>Euomphalus utahensis</i>

* Blackwelder, Eliot.: New Light on the Geology of the Wasatch Mts., Bull. Geol. Soc. America, vol. xxi, pp. 528, 529, 1910.

Brazer limestone.

The Madison limestone is overlain by the Brazer limestone, of upper Mississippian age, named from Brazer Canyon in the Crawford Mountains, 6 miles east by north of Randolph, where it is well exposed. The Brazer for the most part is a massive light-colored impure limestone, but it varies considerably in composition especially in its lower part. In some places much chert is present, occurring in layers a few inches thick and also in irregular bunches. In other localities chert is not conspicuous, and the lower part of the limestone is thin-bedded to shaly. About a mile east of Laketown a thin bed of phosphate rock, formerly assigned to the Park City (Phosphoria) formation, occurs in the shaly lower part of this limestone. The Brazer limestone is more or less sandy throughout, and locally considerable sandstone is present. In the Randolph quadrangle this limestone ranges from 800 to 1400 feet in thickness, which variation suggests an erosional unconformity separating the upper Mississippian from the overlying Pennsylvanian deposits. Fossils are usually scarce in the Brazer limestone. Their occurrence is characteristically bunched, and collections from different localities often show quite different facies. The following species, identified and in part collected by G. H. Girty, were obtained in the Randolph quadrangle:

Fossils from Brazer limestone, Randolph quadrangle:

From $1\frac{1}{2}$ miles east of Laketown, near center of sec. 32, T. 13 N., R. 6 E., and 1 mile south in N. E. $1\frac{1}{4}$ sec. 5, T. 12 N., R. 6 E.:

<i>Endothyra Baileyi</i>	<i>Composita</i> sp.
<i>Zaphrentis</i> sp.	<i>Oliothyridina hirsuta</i>
<i>Productus</i> aff. <i>pileiformis</i>	<i>Concardium</i> sp.
<i>P. Biseriatus</i> ?	<i>Aviculipecten</i> sp.
<i>P. aff. giganteus</i>	<i>Astartella nucleata</i> ?
<i>Dielasma formosum</i> ?	<i>Euomphalus</i> sp.
<i>Girtyella turgida</i>	<i>Holopea proutana</i> ?
<i>Spirifer bifurcatus</i> ?	<i>Griffithides</i> sp.
	<i>Kirkbya</i> sp.
	<i>Paraparchites carbonarius</i> ?

From $1\frac{1}{4}$ miles east of Laketown, near center of W. $1\frac{1}{2}$ sec. 32, T. 13 N., R. 6 E., in shaly limestone near the base of the formation:

<i>Triplophyllum</i> sp.	<i>Productus altonensis</i>
<i>Michelinia</i> sp.	<i>Martinia</i> ? sp.
<i>Rhipidomella</i> sp.	<i>Spirifer moorefieldanus</i>
<i>Chonetes illinoisensis</i> var.	<i>Platyceras</i> sp.
<i>Productella hirsutiformis</i> ?	<i>Paraparchites</i> sp.

Dr. Girty states that the latter fauna is related to that of the Moorefield shale of Arkansas, which is of basal upper Mississippian age.

Pennsylvanian and Permian ? series.

There has been some confusion in the naming of the Pennsylvanian and Permian ? rocks of northern Utah and southern Idaho. The 40th Parallel Survey introduced the term Weber quartzite, taken from a great development of gray quartzite in Weber canyon, for the beds lying between what was called "Wasatch limestone" and the "Upper Coal Measure limestone." Since then down to comparatively recently the name Weber quartzite, without being clearly defined, has been in current usage, but lately somewhat conflicting terms have been introduced for what is thought to be in part the equivalent of the original Weber, although detailed work has not yet been done in the type locality. Boutwell in his report on the Park City District included in the Park City formation beds which may be the equivalent of the upper part of the original Weber quartzite; and Blackwelder, following Weeks, applied the name Morgan formation to a mass of red sandstone and shale with intercalated thin limestone that apparently was included in the lower part of the original Weber quartzite. Gale and Richards, in their Preliminary Report on the Phosphate Deposits in Southeastern Idaho and adjacent parts of Wyoming and Utah, extended the terms Weber quartzite and Park City formation to that region. But as the work in the phosphate reserves of southeastern Idaho was extended, the introduction of new names became necessary because satisfactory correlation with the Weber Canyon section could not be established. Accordingly, Richards and Mansfield introduced the names Wells and Phosphoria formations defined below.

Wells Formation.

The Wells formation,* named from Wells Canyon in T. 10 S., R. 45 E., Idaho, includes the beds of Pennsylvanian age lying between the Brazer limestone and the overlying Phosphoria formation. At the type locality the Wells formation is 2400 feet thick and is divisible into three portions, an upper calcareous sandstone or siliceous limestone series, a middle sandy series and a lower sandy and cherty limestone series. In the Randolph quadrangle, the Wells formation outcrops in only two areas, in the canyon $1\frac{1}{2}$ miles east of Laketown and in the Crawford Mountains. In the former area, where exposures

* Richards and Mansfield: The Bannock Overthrust, Journal of Geology, vol. xx, pp. 689-693, 1912.

are poor, the Wells appears to be less than 300 feet thick, while in the latter area this formation measures 600 feet. Approximately the lower third of the formation is composed of alternating layers of thin-bedded quartzite and limestone, the middle third of massive quartzite, and the remaining upper part of the formation consists of calcareous sandstone and sandy limestone. An unconformity at the base of the Wells formation is indicated by the varying thickness of the underlying Brazer limestone, by the apparent absence in the Randolph quadrangle of a richly fossiliferous horizon near the top of the Brazer limestone, present in the Montpelier quadrangle, and by the absence of the red sandstone, Morgan formation, which occurs at the base of the Pennsylvanian section in Weber Canyon. It should be noted that the thickness of rocks of Pennsylvanian age varies greatly in this general region. In Weber Canyon, Utah, although exact measurements have not been made, there are several thousand feet of beds of that age. This great mass of rocks is reported by Blackwelder* to have disappeared about seven miles north of Weber River. As stated above, in the Randolph quadrangle the rocks of Pennsylvanian age range from less than 300 to about 600 feet in thickness, and in southern Idaho, Richards and Mansfield report the Wells formation to be 2400 feet thick.

Phosphoria Formation.

The Phosphoria formation, named by Richards and Mansfield† from Phosphoria Gulch, a branch of Georgetown Canyon, Bear Lake County, Idaho, includes the phosphate deposits and associated beds of Permian ? age which lie between the Pennsylvanian Wells formation and the Woodside shale of Triassic age. In northern Utah (Randolph quadrangle) the Phosphoria formation is about 400 feet thick. The upper part of the formation consists of chert, cherty limestone, and some intercalated shales from 125 to 200 feet thick, and the lower part is composed of a sequence about 200 feet thick of brown and gray clay shale, subordinate limestone, and layers up to 5 feet thick of oölitic phosphate rock.

At several widely separated localities (noted by Blackwelder‡ north of Weber Canyon, by Richards and Mansfield,§ in Idaho, and exposed in the Randolph quadrangle, a mile north of Brazer Canyon), a zone of breccia-conglomerate is present at or near the base of the Phosphoria formation. This is

* Bulletin, Geological Society of America, vol. xxi, p. 531, 1910.

† Richards and Mansfield: The Bannock Overthrust, Journal of Geology, vol. xx, pp. 684-689, 1912.

‡ Bulletin, Geological Society of America, vol. xxi, pp. 530-533, 1910.

§ Journal of Geology, vol. xx, p. 692, 1912.

marked by angular to semi-rounded bits of chert and quartzite, resembling that of the underlying Wells formation, irregularly scattered through a bed of limestone. That this horizon marks an unconformity separating the Phosphoria and Wells formations is suggested by the varying thickness of the underlying Pennsylvanian beds.

The Phosphoria formation carries an abundant fauna, part of which has been described by Girty.* This is distinctly different from the fauna of the underlying Wells formation and serves as a means of separating the two. The Phosphoria formation is tentatively assigned to the Permian.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Volatile Oxide of Manganese.*—It has been long known that when permanganate is treated with strong sulphuric acid, a small amount of a red vapor or cloud may be discharged from the surface of the resulting green solution. Francke in 1887 decided that this was gaseous manganese trioxide, while soon afterwards Thorpe and Hambly decided that it was not a gas, but a cloud, of the same composition. F. R. LANKSHEAR has now found that in the absence of moisture a colorless gas is evolved from the solution of permanganate in strong sulphuric acid, especially under diminished pressure. By cooling with liquid air he condensed some of this in a U-tube in the form of a dark green crystalline mass which was found to be permanganic anhydride, Mn_2O_7 . He found further that the red cloud was produced when moist air was admitted to a space containing the colorless vapor, and that the red substance, upon being condensed, contained a large amount of water, more oxygen than corresponds to MnO_3 , but less oxygen than is required by Mn_2O_7 . It appears, therefore, that the red substance is an impure product resulting from the reaction Mn_2O_7 vapor with moisture.—*Zeitschr. anorgan. Chem.*, lxxxii, 97. H. L. W.

2. *The Detection of Bromine and its Distribution in Nature.*—I. GUARESCHI has devised a method for the detection of extremely minute quantities of bromine. He has found that fuchsin solution decolorized with sulphur dioxide is the best reagent for bromine, and that paper impregnated with this solution gives an intense blue-violet color with bromine vapor or bromine solution. To prepare the reagent 1^g of fuchsin (hydro-

* Girty, G. H.: The Fauna of the Phosphate beds . . . in Idaho, Wyoming, and Utah. Bull. U. S. Geol. Survey, No. 436, 1910.

chloride or acetate of rosanilin) is dissolved in 1000^{cc} of water and to the solution, with shaking, 8^{cc} of saturated bisulphite and about 10^{cc} of hydrochloric acid of 1.19 sp. gr. are added. To apply the test solid salts are treated with a 25 per cent solution of chromic acid, but carbonates are treated with hydrochloric or sulphuric acid and then chromic acid is added in extremely concentrated solution, so that the dilution may not be too great. The test seems to be applied usually by hanging the test-paper in the neck of a flask in which the bromine is set free. Several aniline dyes may be used in the same way for this test, including Hofmann's violet. The reaction succeeds even in the presence of free chlorine and iodine. When much iodine is present the paper is colored brown so that the blue bromine color is hidden, but the latter appears when the paper is exposed for a short time to the air. By these reagents the author has detected bromine in a large number of substances, including sodium carbonate and bicarbonate, wood-ashes, urine, samples of the purest chlorides and hydrochloric acid.—*Zeitschr. f. analyt. Chem.*, lii, 538.

H. L. W.

3. *Calcium Hydride*.—The observation by Moissan in 1899 that metallic calcium absorbs hydrogen gas at and above a dull red heat, forming a white, crystalline compound of the composition CaH_2 , has led to the manufacture of this substance on the large scale at the electro-chemical works at Bitterfeld for the purpose of its use as a convenient means of producing hydrogen gas for military requirements by treating it with water. It has been found that the hydride may be produced in large solid pieces by leading hydrogen gas into molten metallic calcium, and since the melting point of calcium is at about 800° C. it appears that the hydride must be stable at a rather high temperature. MOLDENHAUER and ROLL-HANSEN, in attempting to determine the pressure of dissociation of this substance by heating it in porcelain tubes, found that it reacted with the porcelain and gave too high results, but by protecting the porcelain with sheet iron, the pressure at 780° C. was found to be 11^{mm} of mercury, while it increased in a regular curve until at 1027° it was 705^{mm}. The results of these experiments indicated also the existence of a second hydride, CaH , more stable than the CaH_2 .—*Zeitschr. anorgan. Chem.*, lxxxiii, 130.

H. L. W.

4. *Analysis of Special Steels*.—DR. S. ZINBERG, Chief Chemist of the Putilow Works at St. Petersburg, has described his method for the gravimetric determination of tungsten, chromium, silicon, nickel, molybdenum and vanadium in the presence of each other in steels. The whole process is too long for description here, but the method for the determination of tungsten, as a first step in the operation, appears to be novel and worthy of notice. One gram of the sample of steel is treated with dilute hydrochloric acid (1:4), by heating, as long as there is any action. The metallic tungsten thus left as a residue is known to contain more or less chromium carbide and iron. The liquid is then

heated nearly to boiling and 2 or 3^{cc} of nitric acid, sp. gr. 1.40, are added drop by drop. A violent reaction takes place by which all the tungsten is precipitated as tungstic acid and all the chromium and iron go into solution. After a few minutes, when the reaction is finished the liquid is diluted, then the precipitate is allowed to settle and is filtered and washed with dilute hydrochloric acid (1:10). In this way, the author states all the tungsten is obtained entirely free from silicon and chromium.—*Zeitschr. f. analyt. Chem.*, lii, 529.

H. L. W.

5. *Qualitative Chemical Analysis*; by ARTHUR A. NOYES. Fourth Edition. Completely rewritten. 8vo, pp. 110. New York, 1913 (The Macmillan Company).—The first edition of this well-known laboratory manual appeared twenty years ago. It has been improved and somewhat enlarged in the second and third editions, and now it has been thoroughly revised as a result of the extended investigations that have been made in the author's laboratory during the past six years. The process of analysis has thus been made much more reliable, so that now it is possible, the author states, to detect one milligram, or in a few cases two milligrams, of any constituent in the presence of 500 milligrams of any other. The methods employed for the detection of the metals are practically all well known and require no special comment here. The procedure for the detection of the acid radicals has been greatly modified by introducing a distillation with phosphoric acid. The first half of this distillate is collected in barium hydroxide solution, the second half in water; then metallic copper is added to the residue and a third distillate is obtained containing sulphur dioxide in case sulphates are present, and applying even in the case of barium sulphate. This distillation with phosphoric acid is not intended to be applied in simpler cases, and it may be regarded as a rather difficult and complex operation for ordinary students in qualitative analysis, and, therefore, its general adoption appears to be doubtful. H. L. W.

6. *A New Fluorescence Spectrum of Iodine*.—The shortest wave-length recorded by R. W. Wood for the resonance spectrum of iodine vapor when excited by the three very intense visible radiations from mercury is 5337.63 Å.U. Hoping to find fluorescence lines of shorter wave-length, J. C. McLENNAN has recently repeated Wood's experiments, endeavoring, at the same time, to obtain more intense illumination, especially in the ultraviolet. Although no new resonance "lines" were found, the investigator's labors were crowned with the discovery of a fluorescent band spectrum of iodine vapor.

The special form of lamp which produced this spectrum may be briefly described as follows: The outer wall was of the usual Cooper-Hewitt design with mercury electrodes. In the end of this wall, which extended some distance beyond the lateral electrode, a hole was made and then a long tube of clear, fused quartz was sealed at the hole in such a manner as to remain coaxial with the surrounding vessel. Thus the inner end of the

quartz tube was not far from the diagonal end electrode of the mercury lamp, while the exposed end of the quartz tube projected some distance beyond the region of sealing. Crystals of iodine were placed in the quartz tube and the latter was then highly exhausted by the aid of a side tube, which was eventually sealed off. Consequently, when the mercury lamp was running, the iodine was simultaneously vaporized and illuminated by the very intense source of radiation. Negatives of the light emerging from the outer end of the silica tube were taken with a quartz spectrograph.

In addition to the ordinary mercury lines coming from the arc in the outer tube the spectrum contained 80 narrow bands, the mean wave-lengths of the extreme bands being 4608 Å.U. and 2129 Å.U. Although the new spectrum could be photographed in less than 3 minutes, the best negatives were obtained with an exposure of one hour. Doubling the latter interval did not bring out anything additional. The following characteristics of the spectrum may be of interest. From λ 4608 to λ 3365 the bands are faint in places and the grouping is somewhat irregular. The seven bands between 3315 and 3175 are particularly well-marked and appear to be equally spaced at intervals of about 24 Å.U. There are four well-defined pairs of bands in the region between 3065 and 2915. From 2900 to 2545 the bands are quite distinct, but the spacing is irregular. The bands of shorter wave-length than 2515 are spaced about 20 Å.U. apart and each band is about 10 Å.U. wide.

In order to show that the new spectrum was due to iodine, the inner tube was thoroughly washed out with methyl alcohol, dried, etc., and a "blank" exposure was taken. The mercury spectrum then came out very strong but not the slightest trace of the bands could be detected. Several other tests were made but the band spectrum could only be obtained when iodine vapor was present. In order to get an idea of the region of wave-lengths in the mercury radiation which excited the resonance bands, the fused-quartz tube was replaced by an equal length of glass combustion tubing closed at the outer end by a plate of crystalline quartz. With this apparatus the bands could not be photographed although the mercury lines came out quite distinctly up to λ 2893.7. "This interesting result shows, in the first place, that the emission of the band spectrum by the iodine vapor could not have been due to an elevation of the temperature of the vapor by the heat from the arc, for the experimental conditions for obtaining a temperature spectrum were precisely the same with the combustion glass tube closed by a quartz window as with the fused quartz tube closed with the same window." Also, the new spectrum does not appear to be directly related to the temperature band spectrum of iodine as obtained by Konen and others. It is thus seen that the resonance bands are excited by radiations of shorter wave-length than 2893.7 Å.U. The exact wave-length of the exciting line has not yet been deter-

mined by McLennan but, at present, the evidence favors the strong mercury line at $\lambda 2536.7$. In none of the experiments with the coaxial lamp were the fluorescence lines discovered by Wood detected. The complete absence of these series lines may be explained as due either to the absorption in the long column of iodine vapor with the temperature gradient down towards the quartz window, or to a different constitution of iodine vapor at the relatively high temperature of the coaxial lamp as compared with the ordinary room temperature in Wood's investigations. At present, there is experimental evidence in favor of both hypotheses.—*Proc. Roy. Soc.*, vol. lxxxviii (A), p. 289.

H. S. U.

7. *Interference of Gamma Rays*.—Since X-rays and γ -rays seem to belong to the same type of radiation and since it has been shown experimentally, by Friedrich, Knipping, Bragg, and others, that the atomic or molecular structure of certain crystals acts like a space grating with respect to X-rays, it is natural to expect a similar phenomenon in the case of γ -rays. This question has been successfully investigated by A. NORMAN SHAW. A general idea of the simple apparatus used may be obtained from the following statements. The bulb which contained about 15 mg. of radium bromide was placed at the bottom of a deep hole bored in a thick block of lead. The primary γ -rays passed through a sheet of lead 2^{mm} thick which covered the mouth of the hole and which prevented the emergence of the direct β -rays. The primary beam continued through a long collimating hole in a second block of lead. A magnetic field was maintained across the outer end of this hole in order to deviate the secondary, "emergence" β -rays from the axis of the beam of primary γ -rays. Beyond the electromagnet the latter rays passed through a hole in a lead screen and then struck a sheet of mica at approximately grazing incidence. The hole in this screen was slightly larger than the one in the collimating block. After leaving the mica the γ -rays eventually struck a photographic plate whose plane was normal to the impinging beam. "It was found that the sensitiveness to γ -rays was increased by placing thin layers of matter" [paper, etc.] "in front of, and almost in contact with, the photographic plate." "More β -particles were thus liberated in the path of any beam of γ -rays near the surface of the plate, and the impression was intensified without an appreciable amount of additional scattering."

In a typical experiment the sheet of mica was 1^{mm} thick and 15^{cm} distant from the photographic plate. The collimating hole had a diameter of 2^{mm}. The time of exposure was one month and hence rays of all intensities down to $1/1500$ of the intensity of the primary beam could have been detected. In general, the central image could be clearly recorded in 40 min. In addition to this circular spot all the negatives show a series of roughly parallel, rectilinear images whose common normal lies in a direction oblique to the intersection with the photographic plate of a plane

perpendicular to the face of the mica sheet and containing the axis of the primary pencil. The number and orientation of these interference patterns are different on the various negatives, due to intentional changes in the sizes and relative positions of the mica, collimating holes, etc. Thus the possibility of interference of γ -rays scattered or reflected at the cleavage planes of mica has been demonstrated experimentally. Three exposures were made with a glancing angle of about five degrees but no grating effects were recorded. The γ -ray negatives were compared both with a negative obtained with X-rays under similar conditions, taken by the investigator himself, and with X-ray photographs taken by Bragg. Shaw says: "Since it is thus apparent that we get faint effects with γ -rays in those directions in which very hard X-rays give their most intense reflections, and no perceptible effect in the direction in which soft X-rays give their strongest reflection, we may conclude that the wave-length of the soft γ -rays from radium is less than that of hard X-rays by an amount not differing greatly from the difference in wave-length between the softest and the hardest X-rays that can be produced with an ordinary bulb and coil." Assuming that the known relation between the velocity of electrons from surfaces and the frequency of the ultra-violet light which liberates them can be extended to γ -rays and to X-rays, and using Planck's formula $\frac{1}{2}mv^2 = hn$, it follows that ordinary γ -rays from radium have wave-lengths probably about ten, or at most a hundred, times smaller than the wave-length of the hardest Röntgen rays.—*Phil. Mag.*, vol. xxvi, July, 1913, p. 190.

H. S. U.

8. *Experimental Researches on the Specific Gravity and Displacement of Some Saline Solutions*; by J. Y. BUCHANAN. Pp. 227. Edinburgh, 1912 (Neill and Co.).—This memoir is reprinted from the *Transactions of the Royal Society of Edinburgh*, Vol. XLIX, Part I, 1912.—"The main purpose of the investigation was to determine the specific gravity of solutions of moderate concentration and of high dilution." The data were obtained by using specially designed hydrometers, and hence a great deal of space is devoted to an account of the construction and manipulation of these hydrometers, and also to the high degree of accuracy attainable. The salts studied with the closed hydrometer were the bromides, chlorides, iodides, bromates, chlorates, iodates, and nitrates of potassium, rubidium and caesium, and also the nitrates of lithium, sodium, strontium, barium and lead. The chlorides of beryllium, magnesium and calcium were investigated with the open hydrometer. The tables are numerous and represent an enormous amount of work which was apparently done in the most painstaking manner possible. The results obtained from the discussion of the numerical data are new and important, but far too numerous to admit of recapitulation in this place. One typical illustration must suffice.

"The most noteworthy case is that of calcium chloride in supersaturated solution. In it a very remarkable state of unrest

was observed before crystallisation took place. When the crystallisation of this solution is finished, the sum of the volumes of the crystals and the mother-liquor is less than that of the original supersaturated solution. The state of unrest which precedes the actual appearance of the first crystal consists in a rhythmic series of *isothermal expansions and contractions*, which cease the moment the first crystal appears and heat is liberated. The supersaturated solution exhibits veritable symptoms of *labour* before giving birth to the crystals and becoming itself a mother-liquor." H. S. U.

9. *Die elektrischen Eigenschaften und die Bedeutung des Selens für die Elektrotechnik*; by DR. CHR. RIES. Second edition. Pp. 189, with 90 figures. Berlin-Nikolassee, 1913 (Administration der Fachzeitschrift "Der Mechaniker").—The present edition of this book was made necessary by the numerous investigations of the properties of selenium, and by the great improvements in the practical applications which have been made in the last four years. Most of the sections have been rewritten and amplified so that the volume has grown to nearly double its original size. Chapters I to XVII inclusive (pp. 1–130) are devoted to the purely physical properties of selenium, while chapter XVIII (pp. 130–160) deals with the practical applications of these properties. The next chapter gives the complete bibliography of the subject, and comprises 388 references which are grouped under the year of publication and then arranged alphabetically according to the names of the authors. The material is presented in such a clear, thorough and systematic manner that the book constitutes a very useful and interesting contribution to the subject. H. S. U.

10. *Photochemische Versuchstechnik*; by JOHANNES PLOTNIKOW. Pp. xv, 371, with 189 figures, 50 tables, 3 plates. Leipzig, 1912 (Akademische Verlagsgesellschaft).—Prior to the appearance of this book there existed no single volume which contained a description of the methods of experimentation and of the apparatus used in photochemical investigations. The present incomplete development of the subject caused the author to state clearly in his preface that the text is not a laboratory manual or practical guide but that, in the nature of the case, it deals only with the technique of experimentation. The value of the book is greatly enhanced by the fact that, under the direct supervision of Plotnikow, the firm of Fritz Köhler in Leipzig has established a new department of photochemical apparatus. Some pieces of apparatus are new and are described for the first time.

As regards details, the material is presented in a very thorough and admirable manner. The first four Parts of the text deal respectively with sources of light, optical thermostats, optical measuring instruments, and photochemical demonstration experiments. The fifth Part comprises a very complete set of numerical tables. Of these, the tables of reciprocal wave-lengths and of $c \cdot \lambda$ deserve special mention. The bibliographical references are

numerous and apparently complete. It is evident, therefore, that the volume will be especially welcome to investigators who contemplate entering the field of photochemistry. H. S. U.

11. *A First Course in Physics*; by ROBERT ANDREWS MILLIKAN and HENRY GORDON GALE. Revised edition. Pp. x, 442, with 463 figures and 659 problems. Boston, 1913 (Ginn & Co.).—In this volume the authors have maintained the method which characterized the first edition and which was largely responsible for its pronounced success. In the preface to the last edition attention is called to the ten most important changes which have been introduced. In brief, most of these alterations are of two general kinds;—(a) improved presentation brought about by shortening and by simplification, and (b) the introduction of a large number of new problems and figures. Furthermore: "The approach to the subject of physics has been made more simple and interesting by postponing the chapter on force and motion until after the discussion of the fascinating phenomena of liquids and gases." The book is made very attractive and inspiring by the introduction of an excellent selection of about forty half-tones of portraits of physicists and of photographs of some of the most notable achievements of modern physics, both in the field of application and of pure science. Also, the number of pages has been reduced by about sixty in order to give opportunity for an extended review at the end of the course. The last edition unquestionably merits the earnest attention of all who are engaged in introducing the subject of physics to students.

H. S. U.

12. *Materialien für eine wissenschaftliche Biographie von Gauss*; edited by F. KLEIN and M. BRENDL. Pp. 143. Leipzig, 1912 (B. G. Teubner).—The material presented in this volume has been very carefully arranged and worked up by L. SCHLESINGER from the original notes and records of Gauss. The subject-matter is divided into two parts entitled respectively, "*C. F. Gauss: Fragmente zur Theorie der arithmetisch-geometrischen Mittels aus den Jahren, 1797–1799*," and "*Über Gauss' Arbeiten zur Funktionentheorie*." The first part, which is preliminary to the second, is in turn subdivided into three sections. The first of these consists essentially in a table of mathematical expressions accurately copied from the original manuscripts. In the second section Schlesinger explains and comments on the formulæ of the preceding list. The last section of this part deals with the probable dates of the results obtained by Gauss. As its title implies, the second and main part of the volume relates to the investigations of Gauss in the field of the Theory of Functions.

Many of the quotations from the original manuscripts are published for the first time, and the whole book throws much light on the various phases of the development of Gauss's ideas and thoughts. Consequently this volume should be very acceptable to all who are interested in the history of mathematics in general, and in that of Gauss's scientific career in particular. H. S. U.

13. *Descrizione di una Macchinetta Elettro-Magnetica*; by DR. ANTONIO PACINOTTI. Pp. 95, with 2 plates. Bergamo, 1912 (Istituto Italiano d'Arti Grafiche).—This little book was published under the auspices of the *Associazione Elettrotecnica Italiana*. It is an extract from the "*Nuovo Cimento*" of June 1864 which appeared May 3, 1865. In addition to the original Italian the text is given in French, English, German, and Latin. The respective translators were Paul Janet, S. P. Thompson, Gisbert Kapp, and P. Rasi. The paper consists in an account of the model of a small electromagnetic machine which was constructed by Pacinotti in 1860 for the Cabinet of Technological Physics of the University of Pisa. As is well known, the work of Pacinotti played an important part in the development of electromagnetic machinery, and hence this collection of translations is both interesting and valuable from the historic standpoint. The first plate is a picture of Pacinotti, and the second plate contains four figures of plans, sections, etc., of the machine. H. S. U.

14. *L'attraction universelle considérée comme fonction du temps*; by A. N. PANOFF. Pp. 6. Reprint from *Astron. Nachr.*, vol. xciv, March, 1913.—The author's reasoning is based on the assumption that gravitational forces, like electromagnetic forces, are propagated with finite velocity. Expressions for the retarded potential and the aberration of the force due to a moving body are developed, and the theory is applied to the orbital motion of the planets. The methods employed do not appear to be essentially different from those introduced by Lorentz into electromagnetic theory, and applied to gravitational fields by numerous authors. L. P.

II. GEOLOGY AND MINERALOGY.

1. *Publications of the United States Geological Survey*.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from p. 77):

PROFESSIONAL PAPERS.—No. 78. *Geology and Ore Deposits of the Philipsburg Quadrangle, Montana*; by WILLIAM H. EMMONS and FRANK C. CALKINS. Pp. 271; 17 pls., 55 figs.

No. 79. *Recurrent Tropicidoleptus Zones of the Upper Devonian in New York*; by HENRY S. WILLIAMS. Pp. 103; 6 pls., 18 figs.

No. 80. *Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah*; by B. S. BUTLER. Pp. 212; 41 pls., 16 figs.

No. 85-A. *The Origin of Colemanite Deposits*; by HOYT S. GALE. Pp. 9.

BULLETINS.—No. 465. *The State Geological Surveys of the United States*; compiled under the direction of C. W. HAYES. Pp. 177.

No. 525. A Geologic Reconnaissance of the Fairbanks Quadrangle, Alaska, by L. M. PRINDLE. With a detailed Description of the Fairbanks District by L. M. PRINDLE and F. J. KATZ, and an Account of Lode Mining near Fairbanks by PHILIP S. SMITH. 220 pp.; 22 pls. (4 maps in pocket), 20 figs.

No. 528. Geology and Ore Deposits of Lemhi County, Idaho; by JOSEPH B. UMPLEBY. Pp. 182; 23 pls., 24 figs.

No. 532. The Koyukuk-Chandalar Region, Alaska; by A. G. MADDREN. Pp. 119; 9 pls., 2 figs.

No. 533. Geology of the Nome and Grand Central Quadrangles, Alaska; by FRED. H. MOFFIT. Pp. 140; 12 pls., 13 figs.

The Yentna District, Alaska; by STEPHEN R. CAPPS. Pp. 75; 13 pls., 7 figs.

No. 540-T. Celestite Deposits in California and Arizona; by W. C. PHALEN. Advance chapter from Bulletin 540; pp. 15; 3 figs.

WATER SUPPLY PAPERS.—No. 292. Surface Water Supply of the United States, 1910. Part XII. North Pacific Coast; prepared under the direction of M. O. LEIGHTON, by F. F. HENSHAW, E. C. LA RUE, and G. C. STEVENS. Pp. 685; 3 pls.

No. 314. Surface Water Supply of Seward Peninsula, Alaska; by F. F. HENSHAW and G. L. PARKER. With Sketch of the Geography and Geology by PHILIP S. SMITH, and a Description of Methods of Placer Mining by ALFRED H. BROOKS. Pp. 317; 17 pls., 12 figs.

No. 318. Water Resources of Hawaii, 1909-1911. Prepared under the Direction of M. O. LEIGHTON, by W. F. MARTIN and C. H. PIERCE. Pp. 552; 15 pls., 4 figs.

2. *Report of the State Geologist on the Mineral Industries and Geology of Vermont, 1911-1912*, by GEORGE H. PERKINS, State Geologist and Professor of Geology, University of Vermont. Pp. xv, 269, pls. 83. Montpelier, 1912.—This volume, well printed and with handsome illustrations, contains a number of contributions. The opening paper is by G. H. Perkins on A General Account of the Geology of the Green Mountain Region, planned as an educational article, especially for the use of teachers. The following paper is on the Geology of the Strafford Quadrangle by C. H. Hitchcock. The rock formations of Irasburg, Craftsbury, and Albany are described by C. H. Richardson, assisted by E. F. Conway and M. C. Collister. Papers on the qualities of the Vermont slate and marbles follow. An interesting discussion on rill channels and their cause is contributed by G. H. Hudson. The volume closes with a statement of the mineral resources by G. H. Perkins. J. B.

3. *The Cretaceous deposits of Miyako*; by H. YABE and S. YEHARA. Science Reports, Tôhoku Imperial University, second ser. (Geology), Vol. I, No. 2, pp. 9-23, pls. III-V, 1913.—An interesting and carefully wrought-out paper describing in detail the very fossiliferous marine Middle Cretaceous beds of the region about Miyako, in the province of Rikuchu, Japan. The

total thickness is more than 600 meters. The various biotas are not yet described, and for the present the correlation with the Cenomanian is provisional. C. S.

4. *Die Antike Tierwelt*; by OTTO KELLER. Zweiter Band: Vögel, Reptilien, Fische, Insecten, etc. Pp. xv, 618; 2 plates, 161 text figures.—This volume completes an extremely valuable work by Otto Keller, of which the first part, that upon the mammals, was reviewed in this Journal for July, 1910. The present is necessarily the more voluminous part, embracing as it does the entire animal kingdom below the mammals, excepting, of course, the Protozoa, which from the nature of things would be outside the pale of the observation of the ancients. The sources of the material are from the literature and from the pictorial arts; sculpture, painting, mosaics—especially those from Pompeii, and from ancient coins and medals.

The book is of great value and importance, though a few errors, mainly of classification, have crept in, such as the placing of the annelid *Aphrodite aculeata* with the myriapods, and the crustacean *Oniscus* and its allies under the annelids. Under the reptiles the "Crocodiles" are made to include not only the true Crocodilia but the huge monitor lizards also. Pearls and pearl fisheries are discussed at length. Printing and illustrations are admirable, greatly enhancing the value of this important work. R. S. L.

5. *A Manual of Petrology*; by F. P. MENNELL. 8°; pp. 256, figs. 124. London, 1913 (Chapman & Hall).—This elementary manual is founded on a former introductory work by the author published some years ago. So little remains of the former publication, however, that it may be considered a new and independent work. It is designed to give a general introduction to the whole field covered by the term "petrology" and consequently suffers those disadvantages which the compression of so much material into such a narrow compass necessarily entails. For the treatment of the rock-forming minerals, their optical and other properties; the origin, classification and description, including their micropetrography, of the igneous rocks, sedimentary rocks, metamorphism in its varied aspects, alteration of rocks, their chemistry; radio-active properties, etc., etc., are all among the subjects included. The author, who is curator of the Rhodesia Museum, and whose field experience has been largely gained in South Africa, has drawn his illustrative material to a great extent from that region, and this gives the work a correspondingly local character.

For classification of the igneous rocks the writer divides them first, geologically into plutonics (large masses), intrusives (dikes), and effusives, and these are subdivided, according to the silica content, into acid (65 per cent +), sub-acid (60-65 per cent), sub-basic (55-60 per cent), basic (45-55 per cent) and ultra basic (-45 per cent). Further subdivision than this he thinks is, at present, to be deprecated.

The author does not believe, to any great extent, in the hypothesis of differentiation, to account for the origin of igneous rocks. He thinks rather that the solution of this problem is to be found in the refusion or melting down on a large scale of pre-existent rocks, and supports his view by what he has observed in South Africa. It would be beyond the limits of this brief notice to attempt an exposition of his ideas regarding the origin and *mise en place* of the igneous rocks, but petrographers, while they may not agree with much that is suggested by the author, will nevertheless find the work of interest and deserving of consideration.

L. V. P.

6. *On a supposed new occurrence of Plattnerite in the Coeur d'Alene*; by EARL V. SHANNON (communicated).—A specimen of a massive mineral apparently corresponding to plattnerite from this district has been presented to me by Mr. Henry Savage of Kellogg, Idaho. The locality is given as the old upper workings of the Mammoth Mine of the Federal Co., located high on the mountain above Mace, where Mr. Savage and Leslie Lamm are operating a lease. Several pounds of the material are said to have been discarded as "iron" and buried in the filling of the worked-out portion of the stope, until, recognizing the great weight of the substance, Mr. Savage brought a specimen to Kellogg and submitted it to Mr. Wm. McM. Huff for examination. The results showed a large proportion of lead and a few preliminary blowpipe tests showed that the lead ore was not one of the more common oxidized products of this metal and it was provisionally considered plattnerite.

The specimen which I was fortunate enough to obtain is a rough nodule covered with ocherous limonite except where fractures show the mineral inside. Some well-bounded mammillary surfaces are present. The interior of the nodule consists of a grayish black mineral of sub-metallic luster and the peculiar greasy look of lead compounds. In appearance the mineral is entirely similar to some forms of compact pyrolusite, and might easily be mistaken for such were it not for the high specific gravity which, judging roughly by comparison, must be 7.5 or 8. The mineral is hard for a lead compound; it scratches apatite but not orthoclase and is hence near 5.5, the compared hardness given for the originally described mineral by Yeates and Ayres. Alone on charcoal it fuses at a low heat and immediately reduces giving a large lead button. No oxide coating is obtained by the reduction, but only upon oxidizing the metallic lead obtained. Heated in the closed and open tube it fuses easily to a brown glass. No sublimate was obtained by heating up to the point where the soft glass became liquid nor was any moisture given off. In the borax bead the splinters were quickly absorbed and formed a bead which in both flames was greenish yellow when hot and clear and colorless when cold.

If the substance is really plattnerite, of which there seems little doubt, it seems desirable to put on record this second definite

known occurrence. It is hoped that further specimens may be obtained for analysis and exchange. The chief credit for the identification rests between Mr. Savage and Mr. Huff, who suggested that the mineral might be the rare lead dioxide. Thanks are due to Mr. Savage for the material supplied.

Kellogg, Idaho.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Müller's Serodiagnostic Methods*; by ROSS C. WHITMAN, B.A., M.D. Pp. 146; 7 illustrations in text. Philadelphia, 1913 (J. B. Lippincott & Company).—This authorized translation of the third German edition of Müller's Serodiagnostic Methods, enlarged by the addition of some of the newer tests in this field, is a "purely practical" manual presenting in a very clear way the methods of "sero-diagnosis." As a compilation of the tests now in use it fills a great need to the worker and student in this line. In each case a brief statement of the theory of the test, followed by the practical applications of the theory, with all the accepted as well as the newer and still untried modifications, is given. A detailed description of the methods makes their performance possible for one inexperienced in this comparatively new branch of diagnosis. As expressed by the author, "The chief emphasis has . . . been laid on making the description of the various methods as exact as possible, and especially on giving a complete and detailed list of the reagents and apparatus required for each test."

The quality of the illustrations is by no means equal to the standard of the rest of the book; by far the best among these being those of the capillary pipettes and capillary tubes for use in some of the tests. References to the original literature in the foot-notes greatly enlarge the value of the book as a reference work. The translator, moreover, has added "certain suggestions offered by experience" now and then, which ought to be of value to the beginner. Among the newer tests in this edition are the following: The Stern test for syphilis, the Much-Holzmann "Psycho reaction," the Müller & Jochmann (modified by Marcus) estimation of the antitryptic power of blood, and the same test according to the method of Bergmann and Meyer. S. G.

2. *Planetologia*; Ing. EMILIO CORTESE. Pp. vii, 387, 64; 12mo, 12 figures, 2 plates. Manuali Hoepli; Milan (Ulrico Hoepli), 1913.—The Hoepli Library has published a series of small volumes, popular in character, on various scientific subjects. The one in hand discusses the planetology of the earth, both from the present and the geological standpoint. Special chapters deal with the internal heat of the earth, the amount of water and the tides, the seismic phenomena, etc. Finally the comparative planetology of other prominent members of the solar system is treated in detail (pp. 297-387).

WARD'S NATURAL SCIENCE ESTABLISHMENT

A Supply-House for Scientific Material.

Founded 1862.

Incorporated 1890.

DEPARTMENTS:

Geology, including Phenomenal and Physiographic.

Mineralogy, including also Rocks, Meteorites, etc.

Palaeontology. *Archaeology* and *Ethnology*.

Invertebrates, including Biology, Conchology, etc.

Zoology, including Osteology and Taxidermy.

Human Anatomy, including Craniology, Odontology, etc.

Models, Plaster Casts and Wall-Charts in all departments.

Circulars in any department free on request; address

Ward's Natural Science Establishment,

76-104 College Ave., Rochester, New York, U. S. A.

EIMER & AMEND

Complete Laboratory Furnishers

Chemical Apparatus, Balances, etc.

C. P. and T. P. Chemicals and Reagents

Platinum Ware, Best Hammered Blowpipe Outfits
and Assay Goods

**WE CARRY A LARGE STOCK OF
MINERALS FOR BLOWPIPE WORK,
ETC.**

EST'D - 1851
203-211-THIRD-AVE
NEW-YORK-CITY

CONTENTS.

	Page
ART. XXXII.—Distribution of the Active Deposit of Radium in an Electric Field (II) ; by E. M. WELLISCH	315
XXXIII.—Adjustment of the Quartz Spectrograph ; by C. C. HUTCHINS	328
XXXIV.—Stability Relations of the Silica Minerals ; by C. N. FENNER	331
XXXV.—Custerite : A New Contact Metamorphic Mineral ; by J. B. UMPLEBY, W. T. SCHALLER, and E. S. LARSEN	385
XXXVI.—Ordovician Outlier at Hyde Manor in Sudbury, Vermont ; by T. N. DALE	395
XXXVII.—Preparation of Tellurous Acid and Copper Ammonium Tellurite ; by G. O. OBERHELMAN and P. E. BROWNING	399
XXXVIII.—Determination of Water of Crystallization in Sulphates ; by S. B. KUZIRIAN	401
XXXIX.—Paleozoic Section in Northern Utah ; by G. B. RICHARDSON	406

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Volatile Oxide of Manganese, F. R. LANKSHEAR : Detection of Bromine and its Distribution in Nature, I. GUARESCHI, 416.—Calcium Hydride, MOLDENHAUER and ROLL-HANSEN : Analysis of Special Steels, S. ZINBERG, 417.—Qualitative Chemical Analysis, A. A. NOYES : New Fluorescence Spectrum of Iodine, J. C. McLENNAN, 418.—Interference of Gamma Rays, A. N. SHAW, 420.—Experimental Researches on the Specific Gravity and Displacement of Some Saline Solutions, J. Y. BUCHANAN, 421.—Elektrischen Eigenschaften und die Bedeutung des Selens für die Elektrotechnik, C. RIES : Photochemische Versuchstechnik, J. PLOTNIKOW, 422.—First Course in Physics, R. A. MILLIKAN and H. G. GALE : Materialien für eine wissenschaftliche Biographie von Gauss, F. KLEIN and M. BRENDL, 423.—Descrizione di una Macchinetta Elettromagnetica, A. PACINOTTI : L'attraction universelle considérée comme fonction du temps, A. N. PANOFF, 424.

Geology and Mineralogy—Publications of the United States Geological Survey, 424.—Report of the State Geologist on the Mineral Industries and Geology of Vermont, 1911-12 : Cretaceous deposits of Miyako, H. YABE and S. YEHARA, 425.—Die Antike Tierwelt, O. KELLER : A Manual of Petrology, F. P. MENNEL, 426.—Supposed new occurrence of Plattnerite in the Coeur d'Alene, E. V. SHANNON, 427.

Miscellaneous Scientific Intelligence—Müller's Serodiagnostics Methods, R. C. WHITMAN : Planetologia, E. CORTESE, 428.

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE,
W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS,
LOUIS V. PIRSSON, HERBERT E. GREGORY
AND HORACE S. UHLER, OF NEW HAVEN,

PROFESSOR HENRY S. WILLIAMS, OF ITHACA,

PROFESSOR JOSEPH S. AMES, OF BALTIMORE,

MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

No. 215—NOVEMBER, 1913.

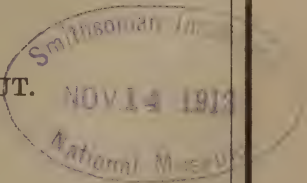
WITH PLATES II-X.

NEW HAVEN, CONNECTICUT.

1913.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. \$6.40 to countries in the Postal Union; \$6.25 to Canada. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).



NEW DISCOVERIES AND NEW FINDS.

BEAVERITE, A NEW MINERAL.

This mineral, which was fully described in the December, 1911, number of this Journal, I have been fortunate enough to secure the whole output of. It was found at the Horn Silver Mine in Utah and is a hydrous sulphate of copper, lead and ferric iron. It was found at a depth of 1600 feet. In appearance it resembles Carnotite. Prices 75¢ to \$2.00.

PSEUDOMORPHS OF LIMONITE AFTER MARCASITE.

These remarkable Pseudomorphs, which have never before been found in such clear cut specimens, was described and illustrated in the last number of this Journal. I have secured the majority of the finest of these specimens. They vary in size from 2 inches to 6 inches. In color they run from brown to glossy black and they have met with favor from all who have seen them. Prices from \$1.00 to \$10.00.

CHIASTOLITES.

Of these remarkable specimens, which are generally known as lucky stones, I have secured the finest lot ever found at Madera Co., California. They are cut and polished and sold singly and in collections from 25¢ to 50¢ for single specimens; 9 specimens all marked differently for \$5.00, and 18 specimens, all different markings, for \$18.00. Matrix specimens, polished on one side showing many crystals, from \$2.00 to \$8.00.

SYNTHETIC GEMS.

It is remarkable the interest that has been taken by scientists in these wonderful scientific discoveries. The Corundums are now produced in Pigeon blood, Blue, Yellow, Pink and White. Also the new Indestructible Pearls in strings with gold clasps. These are identical in hardness and rival in color and lustre the real gems. They can be dropped and stepped on without injury and are not affected by acids. My collection of the above is unrivalled, and prices of the same are remarkably low.

OTHER INTERESTING DISCOVERIES AND NEW FINDS

Will be found in our new Catalogues. These consist of a Mineral Catalogue of 28 pages; a Catalogue of California Minerals with fine Colored Plates; a Gem Catalogue of 12 pages, with illustrations, and other pamphlets and lists. These will be sent free of charge on application.

Do not delay in sending for these catalogues, which will enable you to secure minerals, gems, etc., at prices about one-half what they can be secured for elsewhere.

ALBERT H. PETEREIT

261 West 71st St.,

New York City.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XL.—*The Upper Devonian Delta of the Appalachian Geosyncline*; by JOSEPH BARRELL.

PART I. THE DELTA AND ITS RELATIONS TO THE INTERIOR SEA.*

CONTENTS.

	Page
Introduction and summary	429
Previous views regarding conditions of origin	433
Criteria for separation of subaerial and subaqueous delta deposits	436
Distribution and character of the significant formations	440
Purpose of the descriptions	440
The Oneonta formation	441
The Portage beds	441
The Catskill formation	442
The Chemung formation	446
The Skunnemunk conglomerate	447
The Rensselaer grit	448
The Pocono sandstone	449
Sections of the Catskill-Pocono formations on the Schuyl-kill River, Pennsylvania	450
The Catskill on the Potomac River	459
Reconstruction of physiography and climate of the Catskill delta	463
Comparison of the Catskill and Skunnemunk with the Siwalik formation	463
Conditions of origin of the several Appalachian formations	464
Inferences regarding climate	468

INTRODUCTION AND SUMMARY.

THE Upper Devonian sediments of the Appalachian geosyncline in southeastern New York and northeastern Pennsylvania consist, except at the base, of a great thickness of red shales and gray sandstones known as the Oneonta and Catskill forma-

* Part II on FACTORS CONTROLLING THE PRESENT LIMITS OF THE STRATA and Part III on THE RELATIONS OF THE DELTA TO APPALACHIA will be published in subsequent numbers.

AM. JOUR. SCI.—FOURTH SERIES, VOL. XXXVI, No. 215.—NOVEMBER, 1913.

FIG. 1.

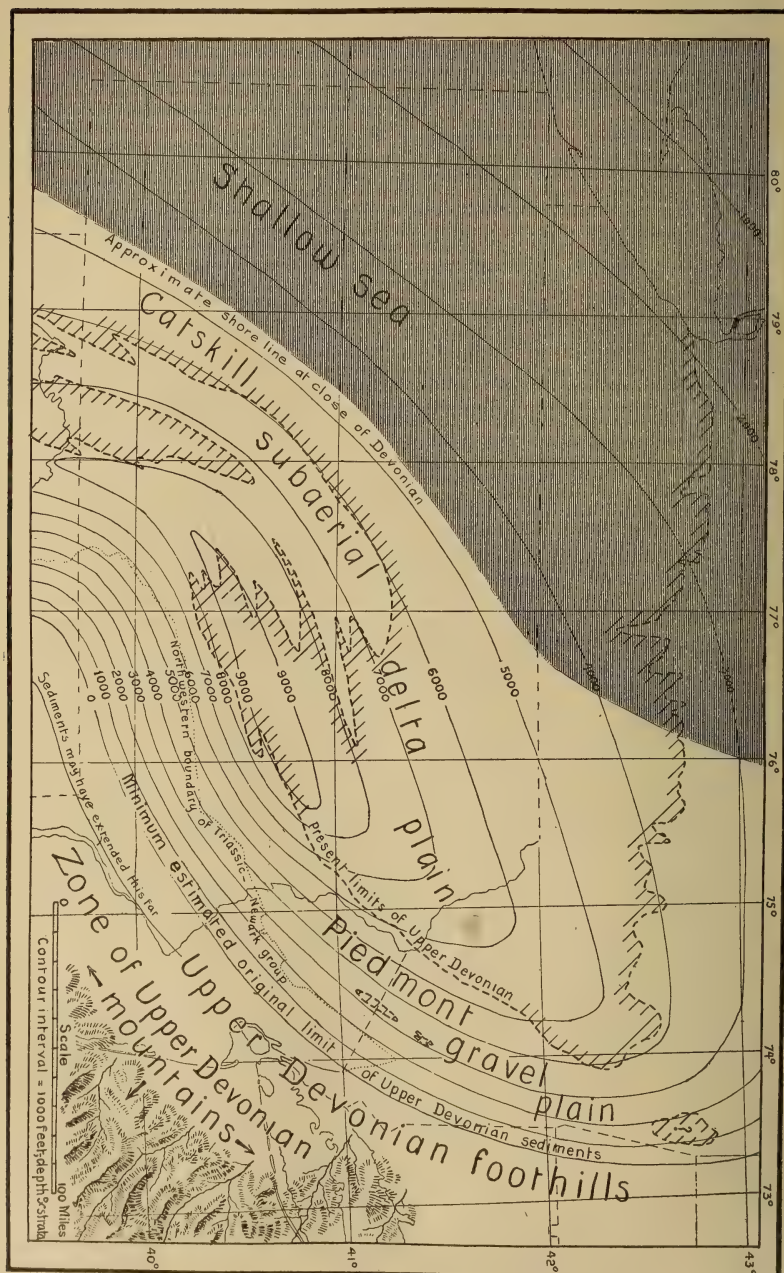


FIG. 1. The Appalachian geosyncline at the close of the Devonian.

tions. These rocks are almost barren of fossils and those which do occur are fragmentary impressions of plants and scanty traces of animal life, none of which is declaredly marine. These barren formations stand in contrast to the fossiliferous dark gray or green Portage and Chemung shales and sandstones which represent the same epochs of geologic time farther to the west and south. The chronologic relations of the formations of the two regions to each other was for a time the chief problem, but that gradually became understood and the equivalences of the Oneonta to the Portage beds, the Catskill to the Chemung, are now universally accepted.

But under what physical and climatic conditions were these several formations laid down? Why are the eastern formations different from the synchronous sands and clays deposited farther west? What causes excluded the preservation of fossils? These are questions to which no unanimity of answers has been given. Even those which have been advanced may be characterized, in most cases, as opinions incidental to geologic descriptions rather than attempts at demonstration. The earlier conclusions furthermore have rested upon premises regarding the processes of sedimentation which in themselves in some respects have either not been sound or not conclusively demonstrated. In an earlier decade the simple dictum prevailed that sediments in general were deposited in permanent bodies of water,—marine, estuarine, or lacustrine, according to the indications of the fossils. But a wider study of the earth has shown the large importance of terrestrial deposition and the view that the eastern formations of the Upper Devonian are subaerial delta deposits, entirely removed from the sea or bodies of permanent water, would not at present appear radical. Yet this is contrary to most of the opinions which have been published during the past twenty years. Furthermore, to obtain scientific standing such a contention must rest upon a basis of demonstration; not merely upon a present appreciation of the larger importance of alluvial deposition; else in another decade the pendulum of opinion may swing backward and carry away from under it the basis for such a conclusion.

The Oneonta and Catskill formations rarely exhibit those obvious and positive evidences which make the demonstration of the conditions of origin of certain other formations relatively easy and sure. During a period of eight years the writer has, however, studied these formations in the field as opportunities arose, examining sections between the Hudson and Potomac rivers. The results of those studies, resting in turn upon other studies on the nature of sedimentation, are embodied in this article and the conclusions are here reached that these Upper Devonian formations represent subaerial delta deposits in a dry but not arid climate; a climate probably

equable in temperature but subject to seasonal rainfall. The conditions over the great delta plain of China facing the shallow, muddy waters of the Yellow Sea may offer the best analogy.

On the west of the Catskill delta plain the shore line oscillated widely and the low alluvial land shaded off through fringing lagoons into a shallow mud-bottomed sea. At the beginning of the Upper Devonian this shore zone was near the present northeastern outcrops. During Portage (Senecan) time the sea retreated widely, but because of lack of deep subsidence of the bottom more than because of rapidity of sedimentation. At the beginning of Chemung (Chataquan) time the sea again advanced, but only to retreat slowly, and at the close of the Devonian the shore line stood in western Pennsylvania, passing diagonally northeast into central New York. This is shown on the map, fig. 1, representing the stage previous to the deposition of the Cattaraugus formation. The contours show the total original depth of Upper Devonian sediments.

In the first part it is the relations of land and sea and the character of the delta which are made the chief object of study. These relations depend for their elucidation upon observations of the strata. The tremendous erosion of the Mesozoic and Cenozoic has aided, not hindered, in drawing the conclusions. Toward the ancient uplands, however, the formations have been completely removed. Here erosion has destroyed the evidence of the original relations. The problem must be approached along converging lines of inferences and by quite different principles of interpretation than those used in the first part. This side of the subject is reserved for Parts II and III, to be published later. Certain of the conclusions are expressed, however, in fig. 1, which applies to the whole. The location of the eastern limit of the sediments is shown as modified by the Permian folding. In its original position it must have been a straighter line with less of a westward deflection in the south.

The length of time through which the writer has studied these formations and the fulness with which they are here discussed are due to more than a mere descriptive interest in the formations themselves; for terrestrial deposits reflect closely the topographic and climatic environments under which they originate and thus furnish a basis for the discussion of larger problems of paleogeography and paleoclimatology.

In closing this introduction the writer desires to acknowledge his indebtedness to Professor Schuchert for the determination of fossils from the section exposed on the Schuylkill River and to Mr. D. F. Hewett for detailed measurements of a part of the same section.

PREVIOUS VIEWS REGARDING CONDITIONS OF ORIGIN.

In order to form a comprehensive background for the discussion of these fossil-barren formations of the Upper Devonian, a review of opinions regarding their conditions of origin, which have been expressed during the past twenty years by geologists mostly still living, will here be given. The diversity of these prevailing views demonstrates the room for further study. It should be said in explanation, however, that certain of the quotations, especially those from manuals, are from geologists, who, although authoritative in their fields, either may not profess to have personal knowledge of the formations in question, or else were not regarding the problem of origin as the principal point in their investigations. Others of the opinions were expressed before the importance of subaerial delta deposits in sedimentation had become appreciated or their criteria recognized and their authors at the present time might modify materially their conclusions. Practically no statements have appeared, however, in regard to the climatic factors which controlled the nature of the deposits, though the present writer holds them to be as fundamental as the coöperating topographic conditions.

J. J. Stevenson in 1891, in his Vice-Presidential address to the American Association for the Advancement of Science, concluded that the deposits of the Catskill epoch were laid down in an open sea, not made in a closed sea or in fresh-water lakes, since the strata are continuous from the Catskill into the Chemung.* The Catskill and Chemung were laid down in a shallow basin subsiding most rapidly at the east with deposits much thicker near the mainland.

"The molluscan fauna of the Chemung and Catskill is unquestionably marine. Even the mollusks found in New York above the Oneonta sandstone belong to the ordinary forms. Of course it is possible, even probable, that at the extreme northeast there were small areas at the mouths of large rivers where fresh water prevailed and fresh-water mollusks lived; but positive evidence of this is wanting. The *Amphigenia* found in the Oneonta sandstone of New York may be a fresh-water form, but it occurs in the Montrose sandstone in southern Pennsylvania so far away from the old shore line that fresh-water conditions seem certainly improbable." (Stevenson, loc. cit., p. 242.)

But the change of view in regard to the conditions of origin of many formations is well illustrated by Stevenson's thorough studies on the "Formation of Coal Beds,"† where he states, in

* The Chemung and Catskill (Upper Devonian) on the eastern side of the Appalachian Basin. Proc. Am. Assoc. Adv. Sci., xl, 1891, pp. 242-247.

† See particularly Proc. American Phil. Soc., vol. li, pp. 243-373, 1912.

connection especially with the deposits of Pennsylvanian age:

"The writer [J. J. Stevenson] has become convinced that one must seek explanation of the phenomena of the Appalachian basin in those of the great river plains of modern times; and the phenomena of the Appalachian basin are those of coal regions elsewhere."*

From this conclusion it is seen that a present-day review of the Catskill problem would probably lead Stevenson to conclusions different from those which he expressed in 1891.

In 1895, J. D. Dana, reflecting the accepted opinion of the time, regarded the Catskill formation as a shore and offshore deposit of the Interior Continental Sea.†

In 1900, Willis‡ states:

"The unassorted mingling of sandy and clayey particles is a result of rapid deposition at the mouths of muddy streams in opposition to waves which are too weak to sort and distribute the volume of sediment. This is a condition of delta-building. In the Devonian sediments as they are now exposed to view the typical contour or profile of any delta may not be observable, but the stratification is not less significant. The frequent and irregular interbedding of coarse sands, sandy clays and clays; the cross-stratified beds, the ripple-marked and sun-cracked mud surfaces, the channels scoured by transient streams, all prove the abundance of the sediments, the shifting conditions of deposition, the irregularity of currents, the wide expanses of tide-flats and shallow waters, and the weakness of the waves. Shallow waters prevailed over an area several hundred miles in extent along the coast and one hundred to one hundred and fifty miles wide from the shore westward."

From these statements and the accompanying map it is seen that Willis recognizes the presence of delta building, but at the same time holds that this was a marine process in that the sedimentation was submarine. Consequently on his map the sea is shown as extending eastward over the Catskill formation.

In 1901 J. M. Clarke discussed the value of *Amnigenia* as an indicator of freshwater deposits during the Devonian of New York, Ireland, and the Rhineland.§ He concludes that this fossil of the Oneonta sandstone, from the associations of the involving sediment, was not marine. From this sediment and other evidence, Clarke states of the Oneonta:

* Loc cit., p. 553.

† Manual of Geology, p. 629.

‡ Paleozoic Appalachia or the History of Maryland during Paleozoic time. Maryland Geol. Surv., iv, pt. 1, p. 63, 1900.

§ N. Y. State Museum, Bull. 49, pp. 199-203.

"The evidence now seems fully to justify the interpretation of this deposit as a sediment accumulated in nearly or quite impounded fresh water or of brackish water cut off from the open sea on the west by a low, shifting submarine bank, not well defined in the stratigraphy save that outside of it flourished a profuse marine fauna; and on the east continuous with and marking the inception of the Catskill sedimentation."*

The Catskill-Oneonta formations are represented in the Green Pond Mountain syncline of northern New Jersey, an outlier twenty-five miles to the east of the Catskill outcrop, by the Skunnemunk conglomerate. Regarding the origin of this conglomerate Kümmel and Weller write of it in 1902 as deposited by the waves and currents of the sea.†

Chamberlin and Salisbury infer in 1906

"That the Catskill region was at least so far shut off from the ocean as not to afford the conditions necessary for marine life. The formation is notable for its redness, a feature which marks many other formations made in inclosed or partially inclosed seas, inland lakes, or basins."‡

In 1906, the present writer, in discussing the factors leading to subaerial delta building, called attention to the favorable conditions existing in the Upper Devonian in New York and Pennsylvania, stating:

"This upper Devonian mountain-building, taken into consideration with the restricted nature of the interior sea of eastern North America between the Cincinnati axis and the eastern border, forms geographic conditions which should favor the development of extensive deltas filling up shallow seas and giving rise to the formation of subaerial deposits. Turning to the strata themselves to find an answer to this suggestion, one notes the sparingly fossiliferous character of the Catskill group of the Upper Devonian and the fact that the few fossils found are those of fishes, Eurypterids (*Stylonurus*), and some fresh-water lamelli-branches (*Amnigenia*), suggesting that, occasionally at least, subaerial deltas may have covered considerable regions, and should be looked for by a critical study of textures and structures."§

Not having at that time especially studied the Catskill, a more positive statement was avoided.

In the same year, Grabau concluded the Catskill to be fluvatile and non-marine on the basis chiefly of the progressive overlap upon the Chemung away from the source of supply of

* Loc. cit., p. 200.

† The Rocks of the Green Pond Mountain Region, Ann. Rept. New Jersey Geol. Surv. for the year 1901, p. 42.

‡ Geology, Earth History, ii, p. 434, 1906.

§ Relative geological importance of continental, littoral, and marine sedimentation. Jour. Geol., xiv, p. 453.

sediment,* the same argument applying to the Mississippian and Pennsylvanian formations on the eastern side of the geosyncline.

In 1909, H. S. Williams speaks of the brackish water sedimentation of the Catskill formation.†

Stose, in 1909, states of the Catskill in Fulton County, Pennsylvania,—

“It is undoubtedly a land or fresh-water deposit replacing the upper part of the marine Chemung. Fresh-water conditions apparently originated in the east and were caused possibly by vast floods from the land, which changed the shallow seas from salt to fresh, and brought detritus from deeply weathered areas.”‡

Schuchert, in 1909, shows a marine strait in the Ithaca-Chemung epoch crossing northern New Jersey over the syncline of the Skunnemunk conglomerate. In the region of the Catskill mountains continental deposits are shown but not on the eastern margin of the sea in Pennsylvania. In the text it is stated that in the northeastern end of the trough the normal marine conditions gave way to vast estuarine flats of red muds.§

In 1912, Schwartz writes of the Catskill on the Potomac River, that

“The surfaces of many beds are rippled-marked and the shales display mud cracks. The sandstones are usually cross-bedded and numerous local unconformities are observable. The features of the rocks of this formation show that they were laid down in shallow terrestrial waters and not in the open sea.”||

CRITERIA FOR SEPARATION OF SUBAERIAL AND SUBAQUEOUS DELTA DEPOSITS.

The opinions which have been quoted regarding the conditions of origin of the Catskill and associated formations show the opposite points of view which may be entertained, each based ultimately upon facts of stratigraphy, but logically divergent because of different bases of interpretation. They make it clear that, before describing the details of the formations concerned, or going forward to their interpretations, a summary must be given of the criteria which are here relied upon to interpret those features. The writer has discussed elsewhere somewhat extensively the conditions controlling the

* Types of sedimentary overlap. *Geol. Soc. Am., Bull.*, xvii, 1906, pp 629-632. Presented before the Geological Society of America, Dec. 1905.

† *U. S. Geol. Surv.*, Watkins Glen-Catatonk Folio, p. 11.

‡ *Mercersburg-Chambersburg Folio*, *U. S. Geol. Surv.*, pp. 12, 16.

§ *Paleogeography of North America*, *Geol. Soc. Am., Bull.*, xx, p. 545, pl. 77, 1910.

|| Stose and Schwartz, *Pawpaw-Hancock Folio*, *U. S. Geol. Surv.*, p. 13.

development of continental as contrasted to littoral and marine deposits and the criteria which may thence be drawn for separating the subaerial from the subaqueous beds of deltas. This article in fact is a logical sequence of earlier papers, and here only a summary of the more important criteria will be given.*

Many features from which an observer may gain an impression as to the mode of origin of a deposit are really not definite proofs. Thus ripple-marked, cross-bedded, and fossil-barren deposits may be developed either beneath a permanent water cover or upon river plains, though doubtless the quantity and quality of their development differ in the two cases.

Red beds have been regarded by some because of their color as evidences of terrestrial deposition; by others, of seas barren of life. Again, they have been cited as indications of a deeply decayed regolith, of a humid climate, or of aridity. The present writer holds that redness in rocks may in fact accompany any of these conditions and is not therefore a criterion by itself of anyone.

Mud cracks and conglomerates have been cited usually as evidences of ancient tidal flats and beaches, but are now observed to occur chiefly in river deposits of continental interiors. Those formed in the littoral zone furthermore except on the fronts of deltas are rather unfavorably situated for geological preservation, and are to be distinguished by associations which are commonly absent in ancient examples. Thus it is clear that it is the character, the quantitative development, and associations of the stratigraphic features which are significant rather than their mere occurrence.

In general, traditional criteria are liable to lead into error, because they become accepted as axioms and are applied without further thought. They lag behind the development of a science, whereas the very word 'research' implies the necessity of continually testing the correspondence of the images of science with nature.

Attention may now be turned to what may be regarded in the present state of knowledge as fairly definite criteria which will be of use in discussing the origin of the Catskill and associated formations.

Marine fossils on the one hand, or abundance of land fossils on the other, furnish of course clear cases save in those minor instances where the blowing inland of sand from beaches or the reworking by rivers of the mud of an abandoned sea flat may have mixed small marine fossils into closely related land

* Relative geological importance of continental, littoral, and marine sedimentation. *Jour. Geol.*, xiv, pp. 316-356, 430-457, 524-568, 1906.

Criteria for the recognition of ancient delta deposits. *Geol. Soc. Am., Bull.*, xxiii, pp. 377-446, 1912.

deposits; or, on the other hand, where dead land animals or plants are floated out to sea. In delta deposits some marginal intermingling wider than the tidal zone may be expected from these actions, and the wide shifting of the shores with variable river building will be expected to add to the marginal gradation. Shore effects will, however, not be recorded at great distances, so that the nature of the subaerial delta phase should be established on its landward side, the marine phase where it also is homogeneous and at a distance from the land. With the character of these separated zones clearly determined, the debatable ground between will usually resolve itself into that which belongs to the sea and that which belongs to the land. The Catskill formation was consequently most studied on its eastern side, farthest from the marine fossils of the Chemung.

Barrenness of a formation in fossils should not be urged as a positive criterion of origin, but scanty fossils in an otherwise barren formation are of the highest importance; for under conditions making fossilization difficult it is highly improbable that organisms not native to the habitat and introduced by the accidents of nature should be the ones preserved, unless it be shown that they have a unique suitability for such preservation.

There are, however, two criteria whose use seems especially applicable to the Catskill and associated formations. First of these are marks of subaerial exposure developed both *broadly* and *vertically* through mechanical sediments. These consist chiefly of mud-cracks, rainprints, and rootmarks. Where these occur in such relations they seem to show conclusively a terrestrial origin and not to represent the littoral facies of a marine or lacustrine formation. Not only, as stated previously, does the shore form at any one time but a narrow border to the accumulating mantle, but except on the front of an advancing delta it is commonly a region of erosion rather than of accumulation. Tidal flats are furthermore flooded and drained twice per day, with the result they are always limited in width and are cut by deep channels. These conditions are quite distinctive from those which are found inland. For over deltas and playa basins on the contrary every part is alternately covered by water and by air for considerable periods of time. Where the climate is suitable mud cracking is developed habitually and on a broad scale.

Mud-cracking in chemical sediments, that is in limestones, must, however, be distinguished in significance from the cracking in claystones. Limestones are carried in solution and their development requires a comparative absence of sand and clay, the mechanical deposits carried by rivers and by waves. The solutions to have sufficient concentration may come from per-

manent water bodies, either lakes or seas. The deposit therefore comes not from the direction of the land, but from the direction of the sea. The cracking goes on between the extreme levels of high and low water and the slight shifting of level is not a tidal but at least a seasonal phenomenon. Such mud-cracking of limestones is a playa phenomenon, and especially in certain earlier ages when the lands were base-leveled and lay awash with the sea, broad areas seem to have been at times marine playas. Marine fossils, often of depauperated facies, occur sometimes in mud-cracked limestones. The nearest approach in the modern world is found, doubtless, in the Runn of Cutch, an area of 10,000 square miles flooded by the sea for a part of the year, during the period of onshore monsoon winds.

In the detection of mud-cracks in ancient formations, reasonable care must be used to avoid mistaking for them a polygonal cracking of the rock arising after its solidification. The two, however, are readily distinguished. True mud-cracks always have a filling, the polygons are irregular but do not show an irregularity constant in one direction. True mud-cracks, although easily separated from simulated features, are, however, often very difficult to detect, as the filling may be identical in nature with the original stratum and weathering furthermore destroys such strata very rapidly unless the shales are interlaminated with sandstones. Rainprints must be separated from the pits made by escaping marsh gas and are more usually marked by a spattered surface of the mud than by a few concave depressions. Rootmarks should show a branching pattern and finer tendrils given off from the larger marks. Footprints may be very obscure, but the test in that case is the regularity of recurrence upon the stratum owing to the stride of the animal.

Finally, a criterion of special application to the outlying syncline of Upper Devonian to the east of the main area is found in the nature of the conglomerates.

Conglomerates now forming which are both thick and widespread are observed to be of fluvial and not littoral origin. This is because rivers are able to carry gravels far out over a subsiding river plain, but the waves, on the contrary, tend to keep gravel banked along the shore. During an advance or retreat of the sea, basal conglomerates may be widely spread, but they are thin, and often wanting, reaching their greatest development among islands or along an irregular rocky shore able to withstand the waves for some time during a rising sea. A maximum limit to widespread basal marine conglomerates seems to be one hundred feet and therefore broad conglomerate formations of greater thickness are evidences of terrestrial

accumulation.* They may of course be of terrestrial origin also when thinner and more limited, but in that case so far as these characters determine they may also be marine.

The criteria previously discussed seem definitive. There are other features, however, which may be regarded as supplemental criteria. For example, river sands are deposited from flowing waters and are more cross-bedded, heterogeneous and current-marked. Marine sands are mostly spread by the oscillations of waves. They tend to be evenly bedded, more cleanly sorted, ripple-marked, and often exhibit a flagstone character. But neither kind of action is restricted wholly to either the land or sea; since shallow seas may be swept with storm-driven currents and marked by shifting bars, and broad river plains when overspread with seasonal floods simulate, for the time, permanent bodies of water. It should be noted here, however, that if the terrestrial origin of the Catskill formation be accepted on the basis of the other criteria, as discussed in the following pages, it tends to show pervasive cross bedding to be a criterion of considerable supplemental value; for the argillaceous sandstones of the Catskill reveal on weathering a very characteristic oblique bedding which the evenly bedded Chemung sandstones, representing the synchronous marine deposits, fail to show.

DISTRIBUTION AND CHARACTER OF THE SIGNIFICANT FORMATIONS.

Purpose of the Descriptions.

The fundamental requirement in scientific method is the separation of facts, principles, hypotheses, and inferences. In the problem in question there is a large groundwork of well-determined information and a presentation of this is needed as a basis for further discussion. The conclusions to which these facts seem to lead have been stated. Consequently their significance will appear as they are presented. To some extent the descriptions furnish the basis for drawing conclusions, but to an even larger extent, if the conclusions be accepted, the facts show what are the accessory characteristics of subaerial and subaqueous delta beds, developed under certain physiographic and climatic conditions.

The delta conditions make themselves evident near the beginning of the Upper Devonian, and the formations, which when pieced together make the ancient delta, are as follows: The Oneonta formation consists of the early terrestrial deposits of eastern New York, the Portage beds being the corresponding marine equivalents; above these come the Catskill on the

* Joseph Barrell. Some distinctions between marine and terrestrial conglomerates. Abstract, Geol. Soc. Am., Bull., xx, p. 620, 1908.

east, the Chemung on the west, holding similar relations. The Skunnemunk conglomerate, an isolated Upper Devonian outlier, twenty-five miles east of the main Devonian areas, is held to represent a fragment of the gravel plain once lying between the delta flats and the ancient mountains.

Mention must also be made of the Rensselaer grit, another outlier in eastern New York near the Massachusetts boundary, although this may not be of Upper Devonian age. Finally, the Pocono sandstone, the lowest Mississippian formation, must be briefly described, since it overlies the Catskill, was formed under somewhat similar conditions, and the Catskill grades into it by beds of passage.

The Oneonta formation.

The Catskill type of sedimentation began in eastern New York, as determined first by James Hall, at the close of the Hamilton and in northeastern Pennsylvania apparently somewhat later, during the Portage epoch.* This lower portion, the Oneonta formation in New York, is largely separated from the Catskill proper by an eastwardly penetrating wedge of Chemung. The equivalent horizon may exist in northeastern Pennsylvania, but the Oneonta has not there been discriminated from the Catskill. It consists dominantly of red shales but with a considerable content of gray, flaggy sandstones. It attains a thickness of a thousand feet in the Catskill Mountains. The sections by Darton show how in passing westward it shades by transition into the thin-bedded sandstones and hard dark shales of the Portage group,† to which in geologic time it is the equivalent.

The Portage Beds.

This group of formations extends from the Genesee black shale below to the Chemung olive shales and sandstones above, measuring in southwestern New York from 1,200 to 1,500 feet in thickness. It constitutes the Senecan group in the present New York classification. It is the upper part which, according to recent correlations, corresponds especially with the Oneonta to the east. At the base of the group black shales and some limestone testify to the slackness of sedimentation. Above they become alternating shales and flags which, according to the dominance of one or the other, permit subdivision into shale, flag, or sandstone formations. The color as a whole is gray, the sandstones lighter than the shales. The bedding

* C. S. Prosser. The Devonian System of eastern Pennsylvania and New York, Bull. 120, U. S. Geol. Surv., 1894.

† The Stratigraphic Relations of the Oneonta and Chemung formations in eastern Central New York. This Journal (3), xlv, 1893, pp. 204, 205.

is very even, lamination is well developed, and strata of sandstone from one inch to three or four feet in thickness are separated by shale layers. The proportion of sand to shale in the same formation is, however, by no means constant from place to place.

Marine fossils are abundant, but the water was commonly shallow. Ripple-marks occur and more rarely examples of cutting and filling during deposition. Certain parallel lines on shale surfaces suggest the marks made by the dragging of floating vegetation over soft mud. The water cover was not, however, universal, for certain horizons in southwestern New York show abundant mud cracking and rainprints in what was at the time a smooth, soft mud.

The Catskill.

This formation, of variable thickness but measured in thousands of feet, extends on the eastern side of the Appalachian geosyncline from the Catskill Mountains of New York into Virginia. Its deposition extended over Chemung time, the uppermost Devonian. On the northeast the Catskill rests directly upon the Oneonta and differs from it on this eastern side in the great development of hard, coarse, cross-bedded, gray sandstones. Among these are intercalated red shales and gray flags. Not more than ten miles west, however, of the eastern edge of the Catskills, the basal Catskill beds pass into basal Chemung. The higher beds of the Catskill progressively advance westward and southwestward at the expense of the Chemung, but do not reach the western boundaries of New York and Pennsylvania. Southward the Catskill and Chemung disappear in Virginia, the whole section thinning out, but the Catskill not reaching as far as the Chemung. It thus appears that the Catskill phase, consisting typically of greenish gray sandstones and red sandy shales, is a marginal type of sedimentation passing into the distal type of gray, flaggy sandstones, and gray or olive shales. The transition is gradual and the line of separation oscillated widely, the marginal type, on the whole, however, dispelling the distal type. The oscillation is well shown on a large scale by the wedge of basal Chemung which penetrates nearly to the eastern outcrops between the Oneonta and Catskill and on a smaller scale by the occurrence of red shale members hundreds of feet below the highest Chemung horizons, the beds of passage commonly covering as much as five hundred feet.

In turning attention to the character of the stratigraphy, it is noted that the Catskill formation consists typically of thick members tens of feet in thickness, alternately of shale, red and

sandy, with sandstones, gray, argillaceous and gritty. On the eastern side of the geosyncline the gray, arenaceous members dominate the formation, especially its upper part, and the red shale sinks to not over twenty per cent of the section. On the west, however, the shale rises in quantity, though it is not so universally red.

Many of the sandstones are feldspathic; others are spangled with mica. They are apt to be clearly separated below from the shales, but grade into red or maroon sandstones and red shales above. Soft, argillaceous sandstones, deep red to pale red in color, form an intermediate type, grading toward the shales. The sandstones also grade in the other direction into hard siliceous grits of greenish color on fresh fracture. These on the east attain a great development and become conglomeratic from the presence of small scattered pebbles of white quartz. A few horizons of coarser and purer conglomerates also occur. The sandstones give rise to ledges, the weathered surfaces revealing oblique bedding of most of the strata and the whole etching into outcrops which have been likened to piles of boards. I. C. White gives a vivid description of the bedding characters for northeastern Pennsylvania, as follows:

"The sandstone beds vary in thickness from 2' to 10' and are characteristically false or current-bedded. The lamination, as exhibited in the cliffs, is very curious. Each of the horizontal beds are crossed obliquely by lines an inch or two apart, weathered into furrows. The slope of the furrows in one bed will be in one direction; that of the beds above and below in the opposite direction. The ends of the furrows meet along the horizontal lines of stratification at an acute angle. Consequently, when a considerable number of these sandstone beds, lying upon one another, are exposed to view, the whole face of the cliff is sculptured in zigzags from top to bottom.

"This false bedding sometimes shows regularly straight and parallel lines; at other times the lining is curved and the laminae overlap each other at the bottom; but at the top they are cut off square."*

Ripple-marking is but rarely observed. Although the sandstones may be sharply separated in many instances from the shales below, and different strata show oblique truncation, they do not commonly exhibit channeling effects. Not infrequently, however, they contain fragments of red shale, originally no doubt as plastic mud, showing in that manner that scour and fill did go on.

* The Geology of Susquehanna and Wayne Counties, Second Geol. Surv., Pa., G-5, p. 60, 1881.

Turning to the shale members, whose redness gives the most striking superficial character to the Catskill formation, they are in most cases arenaceous. The purer shale members exhibit very poor bedding, weathering in a short time into a fine-grained, hackly rubbish with fracture surfaces unrelated to bedding. Many of the sandy shales, however, are fairly well-bedded. Yellow or olive shales are practically absent except in the beds of passage at the top and bottom of the formation, more especially on the western limits of the formation. Details regarding the bedding characters of the shales have been but little described, doubtless owing to their imperfect preservation and still more imperfect exposure. In the extensive literature of the Pennsylvania and New York reports the writer does not know of any allusion to mud-cracks, rootmarks, or rainprints. Mud-cracks receive mention only in the passages previously quoted, by Willis in a general way as present in the formation and more specifically by Schwartz. The bedding features of the shales were, therefore, made a special object of study, and the results with their bearings on the problems of origin will be described in detail in a later part of this paper.

The different sandstone and shale members are horizontally discontinuous, visible but gradual alterations in the thickness and more rarely transitions in color being seen in places in a single outcrop. On a larger scale I. C. White notes of the Catskill in the Susquehanna river region, that the character of the rocks is very changeable; since in one section more than two-thirds of the whole series may be massive-looking, greenish sandstones, with only thin beds of red shale, interstratified; though only a few miles distant the green sandstones disappear and in their stead are found very thick red beds.* In 1881 Dr. I. C. White studied and reported on four sections of the Catskill—on the Lehigh River, through Broadheadsville, along the Lackawanna Railroad, and near Otisville, the latter locality in New York State.† These sections are respectively 14, 32, 42, and 63 miles northeast of the Little Schuylkill section studied in detail by the present writer. In northeastern Pennsylvania White had established certain subdivisions to the Catskill which he carried in these sections to the Lehigh River. J. P. Lesley still further extended this correlation,‡ giving the names in descending order of Mount Pleasant red shale 700 feet, Cherry Ridge conglomerate 200 feet, Cherry Ridge red shale group 1117 feet, Honesdale sandstone 987

* The Geology of the Susquehanna River Region, Second Geol. Surv. of Pennsylvania, vol. G-7, p. 55, 1883.

† The Geology of Pike and Monroe Counties, pp. 73-82, Second Geol. Surv. Pa., vol. G-6, 1882.

‡ Summary, final report, ii, pp. 1596, 1597, 1892.

feet, Montrose red shale 2000 feet, Delaware flags 1200 feet, New Milford red and gray shales and sandstones 700 feet, Starucca flags 600 feet; total, 7544 feet for the Lehigh River section.

In 1882 Mr. Arthur Winslow measured sections in detail from Wilkes-Barre to the Lehigh Gap. His section of the Catskill on the Lehigh River* shows no such division of the Catskill into distinct groups and the character of his section corresponds much more with the one given in this paper for Schuylkill County. Winslow's section and White's observations on the changeable character of the Catskill in the Susquehanna River region† point to the error likely to be involved in such attempted correlations as those of Lesley's and mark out the Catskill as a formation particularly subject to lateral variation of its members. Inconstancy of sedimentation was the rule and is doubtless of significance in connection with its mode of origin.

Measurements of the Catskill by different observers and in different regions cannot well be compared because both the lower and upper limits are indefinite, the Catskill grading into the adjacent formations by beds of passage. Below, on the east it has not been separated in northeastern Pennsylvania from the Oneonta and on the west its base is commonly taken as the lowest prominent red bed. But this horizon varies in nearby localities. On the upper limit the separation from the Pocono sandstones and conglomerates is arbitrary and the Pennsylvania geologists have differed among themselves as to the boundary to the extent of several hundred feet. The top of the last important red shale has usually been chosen as the dividing plane. An idea of the great volume of this formation may be obtained by noting that in the Catskill mountains the portion spared by erosion has a thickness of about 3,000 feet; or 4,000 feet if the Oneonta be included. The base rises stratigraphically on going southwest, but the Catskill and so much of the Oneonta as is represented increase nevertheless to a thickness of 7,500 feet on the Lehigh River in Pennsylvania.‡ On the southern boundary of Pennsylvania, in Fulton County, the Catskill is given a thickness of about 4,000 feet. From these large figures for the eastern outcrops the thickness rapidly diminishes westward, the formation disappearing in western New York and Pennsylvania.

In the region of the New York and Pennsylvania boundaries west of the seventy-eighth meridian, the deposition of red shale continued into the basal Mississippian as shown by marine fos-

* Ann. Rept. for 1886, pt. iv, pp. 1363, 1364, 1887. Summary final report, ii, pp. 1594-1596, 1892.

† Sec. Geol. Surv. Pa., vol. G-7, p. 55, 1883.

‡ I. C. White. Second Geol. Surv. of Pa., vol. G-6, pp. 77, 78, 1882.

sils in intercalated gray bands. In this region consequently the physical conditions of the Upper Devonian are seen to have persisted somewhat after its paleontological close, giving rise to the Cattaraugus formation similar to the Chemung-Catskill transition beds.

Fossils, as previously noted, are extremely rare in the Catskill and Oneonta, consisting in a few strata holding fish scales and teeth, more rarely bones, a bivalve mollusc (*Amphigenia*), a few Eurypterids, and some fragmentary plants. The shales, however, often show a mottled effect suggesting numerous faintly marked worm burrows. In other places discontinuous, thread-like markings ramify in the mudstones. These may come from the rootlets of what was at the time a sod-like cover of vegetation. The fossils show that the fauna was not of the open sea, but on the other hand it has not proved to paleontologists that the Catskill was a subaerial formation unrelated to the sea.

The Chemung.

With the close of Portage time the character of the sedimentation changed somewhat from the preceding, a coarsening in grain and a greater thickness of strata suggesting an acceleration of uplift and erosion in one region, of subsidence and sedimentation in another. On the east more dominantly sandy Catskill beds began to be laid down upon the red shales and gray flags of the Oneonta. Farther west in the Chemung beds the prevailing color changed from the dark bluish gray of the Portage formation to light tones of dull brownish yellow or gray. Greenish tones also occur, but red shales are absent. The tough arenaceous shale of the Portage with knife-like edges was succeeded by a comparatively soft shale cracking into blocky fragments. With these shales are intercalated thin beds of sandstone. Calcareous argillaceous sandstone bands occur, many of them fossiliferous, weathering to a porous texture. Thin bands of conglomerates appear at several horizons and these considering their thinness are widely persistent. Many horizons of marine fossils exist.

The chief distinctions from the contemporaneous Catskill are found in the evenness and continuity of bedding, the more argillaceous and in places calcareous nature, but more strikingly in the absence of red beds and in the presence of marine fossils. The Chemung has a thickness ranging from 1,100 to 1,400 feet in western Pennsylvania and southern New York. In central Pennsylvania it reaches 2,000 to 3,000 feet, but has not been separated clearly from the Portage. Including the latter, the thicknesses reach from 3,000 to 4,000 feet. The Jennings formation in western Maryland, equivalent to the

Portage and Chemung, attains thicknesses measured from 3,500 to 4,400 feet.

The Skunnemunk conglomerate.

In Passaic County, New Jersey, and in Orange County, New York, occurs an isolated, down-faulted and down-folded syncline of Paleozoic rocks known as the Green Pond Mountain axis. It lies 20 to 25 miles southeast of and parallel to the margins of the main area of Devonian rocks. It is about 50 miles long, from 1 to 4 miles in width, and through most of its length is hemmed in by uplands of pre-Cambrian gneiss. The synclinal axis includes formations ranging from Lower Cambrian to upper Devonian and gives information respecting the conditions existing during the deposition of the neo-Paleozoic formations 25 miles nearer to the old land of Appalachia than is seen elsewhere in this part of the Appalachian geosyncline. Above the Bellvale flags holding a marine Hamilton fauna, lies the massive Skunnemunk conglomerate of Upper Devonian age which Darton was the first to discriminate from the somewhat similar Green Pond conglomerate of the Silurian.

"The typical beds of the Skunnemunk formation are a coarse, purple-red, massive conglomerate, the pebbles of which are some times six or seven inches in diameter. Beds of red sandstone alternate more or less frequently with the conglomerate, and there are many gradations between the two. In the conglomerate the most conspicuous pebbles are white quartz, owing to the contrast they present to the dull red matrix. Dark red quartzite and sandstone pebbles are, however, almost as abundant as the quartz pebbles, and red shale pebbles frequently occur. In some of the lower layers green sandstone or graywacke pebbles are also abundant. The varicolored cherts which were noted sparingly in the Green Pond conglomerate were not observed here. The matrix is in general the same material as the pebbles, only finer, and is firmly cemented together, sometimes so much so as to present a vitreous appearance. On the whole, however, this formation is not so vitreous and quartzitic as the Green Pond conglomerate. The rock is locally traversed by many white quartz veins, which add greatly to the contrast of colors and the variegated appearance.

"Although this formation is typically a very massive dark red conglomerate, forming innumerable ledges and cliffs in the region underlain by it, yet in its lower portion it contains many beds of red shale and sandstone as well as green flags and greenish conglomerates.

"Since these conglomerates rest upon the Bellvale flags, which are of Middle Devonian age, they must be somewhat younger. Darton has suggested that they correspond to the Oneonta forma-

tion in central New York, or that they are 'equivalent to the coarse beds of Chemung age in the southern Catskills.'**

This formation has everywhere an eroded top but still in the deepest part of the syncline retains a thickness of 2,500 feet.

The Rensselaer grit.†

Between the Hudson River and the northwestern side of Massachusetts stretches a tableland known as the Rensselaer Plateau. It is underlain typically by a dark green grit or graywacke, in some beds calcareous, in others conglomeratic. The conglomerates are rather fine-grained, the pebbles rarely reaching an inch in diameter, and are angular or subangular fragments of quartz, feldspar, gneiss, slate, and red quartzite; the relative abundance being in the order named. Some dark purple or reddish slates occur and rarely angular fragments of limestone in certain conglomerate beds. The formation rests unconformably on the Cambrian and Ordovician formations, as shown by the character of the conglomerates more clearly than the structure, but another orogenic disturbance has followed its deposition, producing folding and metamorphism. Dale notes that measurements of the total thickness are especially difficult to make, but estimates that in one exposure at least 2,000 feet remain.

The formation is younger than the Ordovician and was formerly assumed to be of early Silurian age, but as the result of studies by the New York geologists, John M. Clarke expresses the opinion that

"The evidence compels us to grant that the Rensselaer grit is of later than Siluric age; there is some good reason for regarding it an eastern deposit contemporary with the early Devonian, but the alternative proposition stands open, that its estuarine character and great thickness suggest identity with the Catskill beds which stand sheer on the other side of the Hudson River in heights of several thousand feet and only 30 miles away from the outlier at Austerlitz."‡

From this view the present writer would differ slightly. The argillaceous component of the Oneonta and Catskill beds is colored red and stands in contrast to the grays, greens, and yellows of their marine equivalents. In the Middle Devonian, however, the marine muds are dark gray to black, and the

* Kümmel and Weller. Annual Report of the State Geologist of New Jersey for 1901, pp. 23, 24.

† See T. Nelson Dale, The Rensselaer Grit Plateau in New York. U. S. Geol. Surv., 13th Ann. Rept., Pt. II., 1893, pp. 291-340.

‡ Early Devonian history of New York and eastern North America. N. Y. State Museum, Memoir 9, II, pp. 160, 161, 1909.

coarser marginal deposits, such as the Bellvale flags of the Green Pond Mountain syncline, are also carbonaceous and contain their iron chiefly in ferrous form. In this respect the Rensselaer grit resembles the Bellvale flags much more than it does the Oneonta or Catskill formation. In the Hamilton formation a thick and widespread sand and mud mantle holding marine fossils was spread over the northeastern part of the geosyncline, synchronous with the deposition of the Bellvale flags. Erosion was therefore active, and coarser flags and grits should mark the marginal deposits. The reference of the Rensselaer grit to the Middle Devonian seems then more probable from both its color and its arenaceous character. The presence of calcareous beds gives a further contrast to the adjacent upper Devonian deposits.

Interpreted as of Middle Devonian age, the formation would not fall within the limits of this article, save for its indications of the extension of the basin of sedimentation in this direction and the possibility that truly Upper Devonian sediments may have constituted the upper part of the sequence. If such was the case they have been subsequently eroded because lying during the Mesozoic above the baselevels of the time.

The Pocono sandstone.

The Mississippian period was opened by the development in the Appalachian geosyncline of a great sandstone formation, the Pocono sandstone. In character it is distinct from the preceding Catskill, though grading into it through a thick transition series. It consists in the east almost entirely of coarse, clean, gray-green sandstone, verging into conglomerates. These sandstones in some beds become white and platy on weathered surfaces. Other beds are massive. On account of the uniformity of the material such features as crossbedding are not easily detected. Red shales are absent except as very minor developments; but the argillaceous material gives rise, on the contrary, to olive-green or dull yellow shales. Toward the west and southwest the formation thins down, becomes more shaly, and breaks up into a group of alternating shales and conglomeratic sandstones. Thin coal seams become more abundant, but there are also larger members of red shale than to the northeast.

In Allegheny and Cattaraugus counties of New York the Oswayo formation is lithologically equivalent to the Pocono and carries a marine fauna. Marine fossils also occur in Bedford County in southern Pennsylvania. These and other occurrences show truly marine phases occurring in the Pocono in the two-fifths of Pennsylvania west of the seventy-eighth meridian.

In this region of marine deposition the sands, by virtue of their cleanness and porosity, carry brine and oil. Some gypsum is also known from the Waverly group of Ohio. In the eastern half of the state, however, marine fossils and these other associations are not present. From a thickness of some hundreds of feet in the western part of Pennsylvania, it increases eastward, reaching a maximum of about 2,000 feet in the eastern central part of the state.

SECTIONS OF THE CATSKILL-POCONO FORMATIONS ON THE
SCHUYLKILL RIVER, PENNSYLVANIA.

The published descriptions of the Catskill do not conclusively prove its mode of origin and are especially lacking in the mention of the marks of subaerial exposure. Consequently the writer in his field observations has paid especial attention to features and places of significant character, aiming to see especially if the marks of subaerial exposure were probably absent or merely difficult to observe. For reasons which have been discussed, the mode of origin, if of the nature of a subaerial delta plain, is least open to doubt in regions where the deposit is thickest and farthest removed from the marine facies. Excellent exposures have recently been made by the work on the Lackawanna railroad in straightening the tracks between Scranton, Pa., and Binghamton, N. Y. An examination was made in 1913 of these fresh cuttings and the huge fillings of fresh rock waste. Numerous carbonized plant impressions, some of tree trunks, others of more delicate vegetation, were found in gray sandstones. Rainprints and mud-cracks were not uncommon in the red shales and red argillaceous sandstones. In this region, however, the beds are nearly flat and not adapted to the study of a complete section of the formation. On the eastern side of the southern anthracite coal basin, on the contrary, the folding exposes complete sections in the region of maximum thickness in short distances, and these outcrops, furthermore, are those in Pennsylvania which lie nearest to the old uplands of Appalachia whence the sediments were derived. For these reasons, from 1908 to 1912 these sections of the Catskill and Pocono were studied in detail in Schuylkill County of Pennsylvania. Three branches of the Schuylkill River cross the formation in steep-sided gaps; the rocks are admirably exposed by the cuttings of the several railroads which seek every entrance into the anthracite basins; the beds stand vertical, almost uncomplicated by faults or minor folds and through a thickness of three miles of strata record the succession of geologic events from the Middle Devonian into the Pennsylvanian period. The section of the Pottsville conglomerate has

been given in detail by David White; the present writer has elsewhere described this section of the Mauch Chunk formation, and here is added a detailed view of the Upper Devonian and lower Mississippian strata.

The Portage-Chemung and lower Catskill strata are best displayed on the main branch of the Schuylkill River between Schuylkill Haven and Pottsville. The upper beds of the Catskill are best observed on the Little Schuylkill south of Tamaqua, fifteen miles northeast of the other section. At both places the entire thicknesses can be measured, but the beds were studied in detail only where best exposed in each. It is quite certain that in this distance there is some variation in total thicknesses and no exact correlation of individual members, but this error in passing from one section to the other was more than offset by the advantages found in studying the beds for the purposes of this article.

The entire distance of two miles through the Upper Devonian and lower Mississippian was controlled by tape measurements and the thicknesses corrected for the angles between the courses and the strike and dip. The details were fitted on to this control by pacing, since in such unfossiliferous and variable beds nothing would be gained by the minuter accuracy of measuring individual strata by tape or rule. The most definite horizon from which to measure in this section is the top of the Pocono sandstone, coarse gray-white sandstones giving way at this level to the thick red shales of the Mauch Chunk formation. This was therefore taken as the datum plane in the two Schuylkill County sections.

The printed section is made to some degree graphic by offsetting the lines to the right to represent the gradations in texture from conglomerate through sandstone to shale. The color is a significant feature and this is brought out by printing red sandstones and shales in heavy-faced type. The recurrence of evidences of subaerial exposure in the form of mud-cracks and rainprints is made prominent by marginal asterisks.

POCONO—CATSKILL SECTION.

South of Tamaqua, Pa., on the Little Schuylkill River, west side.

MAUCH CHUNK SHALE AND SANDSTONE FORMATION WITH BASAL BEDS AS FOLLOWS:		Thick- ness	Sum	Depth below top of Pocono
Red sandstone shading to gray; the highest gray- ish sandstone in basal Mauch Chunk.....		28		
Red shale.....		6		
Red sandstone.....		11		
Gray sandstone, crossbedded.....		21		
Red shale.....		1		
Gray sandstone, crossbedded.....		16		
Red shale with gradations into flaggy red sandstone. The base of the Mauch Chunk		63	146	

	Thick- ness	Sum	Depth below top of Pocono
POCONO SANDSTONE (its top taken as the datum of the Pocono-Catskill section).....			0
Gray-white gritty sandstone with scattered white quartz pebbles, 0.5 to 1.0 in diameter, maximum 2 in., fairly well rounded. The pebbles are in places concentrated into conglomerates which fade out above. The bases of the conglomerate beds are better defined: two such occur at -100 and -360	720		
Thick beds of conglomerate and grit.....	100		
Gritty sandstone, less conglomeratic.....	90		
Massive conglomerate resembling the Pottsville, pebbles white quartz, rounded, irregular, tending to prolate ellipsoids, average 0.5 in., maximum 1.5 to 2.5 in.	40	950	-950
POCONO-CATSKILL TRANSITION BEDS. Probably to be correlated with the Catskill of I. C. White, with the Pocono of Winslow.			
Gray and olive sandstones with some pebble beds, more argillaceous than the adjacent members and making talus slopes. Some red shale. Not well exposed on this section..	680		
Olive green sandstone, ferruginous.....	83		
Olive green sandstone.....	207	970	-1920
CATSKILL FORMATION (<i>limited by the occurrence of important red beds</i>).			
UPPER SHALY MEMBER. <i>Makes a saddle between the Pocono and Catskill ridges. About 25 per cent red shale.</i>			
Light brown sandstone shading above into a soft massive red shale.....	16		
Olive green sandstone.....	5		
* Pale red shales showing mud cracks of rather small pattern in upper portion..	83		
Olive green shales and sandstones shading at the bottom into red shales.....	47		
* Bright red shale with clear mud cracks....	23		
Shaly sandstone, red.....	35		
Olive green to gray sandstone, no shale.....	28		
Bright red shale.....	28		
Bright red sandstone.....	10		
Bright red shale.....	10		
Red sandstone, shaly in layers, possibly mud cracked.....	80		
Greenish sandstone weathering yellowish gray, muscovitic, transition at top but sharp below.....	105		
* Red shale and sandstone; sandstones ripple-marked; shales with mud cracks and probable rainprints.....	30		
Greenish gray sandstone passing into red above and below through 10 feet of transition beds..	40		
* Red sandstone and shale interbedded, showing mud cracks, a red pattern on a mottled red and yellow surface. Rain prints. These marks better exposed near the top.....	90	630	-2550

This section, from -1920 to -2550, was measured in detail by Mr. D. F. Hewett in April 1911.

	Thick- ness	Sum	Depth below top of Pocono
RESISTANT MIDDLE CATSKILL MEMBER. <i>Makes the Catskill ridge. About 10 per cent red shale.</i>			
Resistant reef of conglomerate and gray to purple cross-bedded sandstones. The lower half more conglomeratic, irregularly rounded pebbles of white quartz. Average diameter 0.5 to 1.0 in., maximum 1.5 in. A prominent local horizon making the crest of the upper Catskill ridge flanking the higher Pocono ridge.....	40		-2590
* Red shales with probable mud cracks.....	30		
Purple sandstone.....	17		
Gray to olive green sandstone.....	20		
* Red shales with suggestions of mud cracks..	20		-2677
Exposure stops on west side of river.			
SECTION ON EAST SIDE OF RIVER BEGINNING WITH -2677.			
Soft red sandstone, 102 feet thick, the upper 87 feet equivalent to section given on west side.....	15		-2692
Olive sandstone with transition beds at top.....	145		
Red argillaceous sandstone.....	17		
Reddish brown sandstone, thick bedded.....	20		
Olive sandstone, with scattered pebbles.....	83		
Brown sandstone, conglomeratic, with scattered pebbles 1 in. in diameter, and clay fragments.....	30		
Olive sandstone, hard, flaggy.....	20		
* Red shale and maroon sandstone, suggestions of mud cracks in lower and more sandy part.....	31		
Light gray quartzite conglomerate, beds 2 to 3 feet thick. Subangular to subrotund pebbles of white quartz, 0.25 to 0.75 in. in diameter..	25		
Reddish brown mudstone.....	10		
Maroon brown hard sandstone.....	23		
Hard greenish gray flaggy sandstone with some transitions into brown sandstones, red argillaceous sandstones, and some pebbly beds with white quartz pebbles, average diameter 0.25 in., maximum 0.5 in.....	345	891	-3441
<i>Base of the most resistant portion of the Catskill.</i>			
Maroon sandstone passing above into red shale.....	20		
Resistant mouse-gray flaggy sandstones with tones of brown. Some current marks.....	286		
Olive gray shale replaced largely to hematite..	3		
Mouse-gray sandstone, mostly hard, some cross-bedding and current marking.....	195		
* Red shale with several clearly marked mud cracked surfaces.....	15		-3960
Clear gray gritty sandstone becoming argillaceous in upper 20 feet.....	70		
Concealed.....	170		
Brown sandstone, flaggy and argillaceous.....	60		
* Red shale, shows what are probably mud cracks.....	5		-4265
Red brown sandstone, argillaceous.....	38		
Olive sandstone, thin bedded.....	155		
Red shale, some suggestions of mud cracks..	62		
Red shaly sandstone.....	10		-4530

	Thick- ness	Sum	Depth below top of Pocono
Olive sandstone, thin to thick bedded, inter- bedded with smooth siliceous shales -----	310		
Gray sandstone, coarse grained	42		
Gray conglomerate, pebbles up to 0.5 in.	12	1455	-4896
<i>Base of more arenaceous and resistant Catskill.</i>			
WEAKER MIDDLE CATSKILL MEMBER. 20 to 25 per cent red shale.			
Red argillaceous sandstone varying from maroon sandstone to red shale, some cross- bedding	74		
* Red brown sandy shale, obscurely mud cracked	40		-5010
Pale brown sandstone	22		
* Red brown shale with obscure rainprints, mud cracks, and marks of rootlets	40		-5072
Maroon to gray sandstone, hard and thick bedded ..	15		
Red shale, soft and massive	11		
Argillaceous red sandstone and shale, well bedded	50		
Concealed	152		
Olive gray sandstone	113		
Red shale	23		
Red argillaceous sandstone	15		
Olive gray sandstone	45		
No exposure, largely olive gray sandstone, argillaceous	162		
Olive gray sandstone, thick bedded, weathering yellow	167		
Red sandy shale interbedded with red argil- laceous muscovitic sandstone. The shale is without good bedding and in places has irregular yellow lines lacing through it... ..	121		
No exposure	594		
* Red argillaceous sandstone (mud cracks at -6595 in the Schuylkill River section south of Pottsville)	250		-6790
Yellow shale, sandy	54		
Yellow argillaceous sandstone	36		
Red shale	50	2034	-6930
Yellow argillaceous sandstones and red shales extend some hundreds of feet below. Ex- posures poor and structure irregular.			
SECTION OF BASAL CATSKILL ON THE SCHUYLKILL RIVER, SOUTH OF POTTSVILLE. Mostly shales, red in upper portion. 15 miles southwest from the Little Schuylkill section.			
Section begins at -6880			-6880
* Red lustrous shales, well bedded, showing mud cracks and rainprints, the mud crack fillings without luster	70		-6950
Olive shales with plant remains	20		
* Red sandstone, argillaceous, thick bedded, some layers mud cracked	25		-6995
Red shales, fissile to massive	55		
Argillaceous sandstone, greenish gray	25		
Red shale showing in soil but section not ex- posed in detail	225		

	Thick- ness	Sum	Depth below top of Pocono
Crossing of wagon road and Lehigh Valley R. R. at elevation 590 and one-half mile N.N.W. of Conner's Station on P. & R. R. R. is at stratigraphic level -7310.			
Red shale and sandstone	140	560	-7440
CATSKILL—CHEMUNG TRANSITION BEDS.			
Olive shale weathering pale yellow, highest Chemung facies but probably not marine.	34		
Olive sandstone.....	12		
Red sandstone	6		
Red shale	23		
Olive shale.....	40		
No exposure.....	150		
* Red sandstone and shale interbedded. Lowest thick red beds and therefore the base of the Catskill	70	335	-7775
Mud cracks and rainprints were found by Dr. A. M. Bateman and the writer in 1912 four and a half miles southeast by east of this point at Landingville in the basal red shale exposed in that section.			
CHEMUNG FORMATION, PASSING BELOW INTO THE SENECAN (PORTAGE) GROUP. Gray and olive sandy shales in upper portion, but the base of this member need not correspond with base of New York Chemung.			
Yellowish gray shale.....	59		
Red shale	1		
Pale red sandstone	10		-7845
Yellowish sandstone in soft olive shales.....	15		
Soft bluish gray shales.....	70		
Not exposed, mostly soft gray shales.....	293		
Sandy gray and olive shales and some sandstones with marine fossils, collected from surface rock about -8250 to -8450. Section not exposed.			
F. Crinoid ossicles and columns. <i>Spirifer mesastrialis</i> ?.....	235	683	-8458
Flaggy sandstones interbedded with dark siliceous shales.			
Dark gray shales and flaggy sandstones, not well exposed	132		
A probable error introduced here of 25 or 50 feet and affecting the stratigraphic level of the beds below. Strata affected by a local fold below this member and one omission made in measurement.			
E. An abundance of crinoid stems and two species of pelecypods.....			-8590
Dark gray shales and flaggy sandstones	65		-8655
Red shale and brown sandstone. The lowest red shale	25		-8680
Thick bedded olive sandstones with thin bedded olive shales. Some conglomeratic beds holding pebbles of white quartz up to 0.5 in. in diameter. Some coarse plant impressions.....	100		-8780

	Thick- ness	Sum	Depth below top of Pocono
Dark flaggy sandstones and blackish gray siliceous shales. The bottoms of the sandstones show ripple marks. Fossils collected at the following levels :-----	555		
D. In sandstone, fragmentary land plants,-----			—9100
C. In siliceous shales, <i>Spirifer mesastrialis</i> , <i>S. sculptilis</i> , <i>Camarotæchia contracta</i> , <i>Coleolus acicula</i> -----			—9127
B. In fine grained sandstone, large <i>Spirifers</i> much like <i>S. granulosus</i> . <i>Tropidoleptus carinatus</i> may be present. In siliceous shales, small fossils of <i>Spirifer sculptilis</i> , <i>S. granulosus</i> and <i>S. mesastrialis</i> ----			—9160
A. In fine grained sandstone, a small <i>Spirifer</i> , probably <i>S. sculptilis</i> , <i>Camarotæchia contracta</i> , <i>Coleolus acicula</i> -----			—9204
Gray black, ripple marked siliceous shales. Exposure ends at Conner's Station, P. & R. R. R.-----	165	1042	—9500
The south side of the station, north side of the wagon road, is at —9500.			

Fossils determined by Professor Charles Schuchert from material collected by Joseph Barrell.

The section, which will be discussed from the bottom upward, begins with the shales exposed at Conners station on the Philadelphia and Reading Railroad, one mile northwest of Schuylkill Haven. This is stratigraphically somewhat below the crest of the ridge made by a series of hard dark flaggy sandstones from which strata fossils were collected at three levels, A, B, C, within 75 feet of each other. According to Professor Schuchert, locality A indicates Portage; B, Portage and Chemung; C, Chemung. A sharp delimitation is difficult since it has been found that in eastern New York certain elements of the Hamilton fauna persist through Portage time and even into the Chemung, *Spirifer sculptilis* being such a form. The synchronous relationships of these eastern and western faunas are brought out by H. S. Williams in the Watkins Glen-Catatonk folio, U. S. Geol. Surv., p. 6, 1909. The fossiliferous beds of the Schuylkill River section cannot be above lower Chemung since *Spirifer disjunctus* is absent. Of the two fossils *Camarotæchia contracta* and *Coleolus acicula*, found together at horizon C, the first occurs only in the Chemung of Williams's lists, the second only in the Portage. From the lithologic standpoint the flaggy sandstones and dark siliceous shales are of Portage character; the soft gray and olive sandy shales above are Chemung in type. The division plane between the two types is, however, known to be

oblique, the Chemung sediments appearing lower down toward the east. It is to be noted that the Jennings formation as seen a hundred and thirty miles southwest in the Pawpaw-Hancock quadrangles is also stated in the folio of that region to contain Chemung and Portage faunas.

In eastern New York the Oneonta gray sandstone and red shale marks there the beginning of Catskill conditions early in Portage time. This section, one hundred and fifty miles to the southwest of the New York exposures, shows that the Oneonta is missing even on the eastern outcrop. Catskill conditions did not begin here until in Chemung time. The progressive change toward the southwest is seen further in that the Jennings formation, the marine upper Devonian of Virginia and Maryland, is at least twice as thick in Maryland as in Schuylkill County of Pennsylvania. Catskill sedimentation did not begin in Maryland until still later.

The transition beds at the base of the Catskill are marked by the occurrence of gray or olive shales of Chemung type interbedded with Catskill red shales. These are well exposed on the flank of a minor syncline at Landingdale on the Schuylkill River a few miles southeast of the detailed section. The significant feature to be observed here is that olive shales occur both above and below a horizon of red shale and sandstone. Marine fossils occur in that

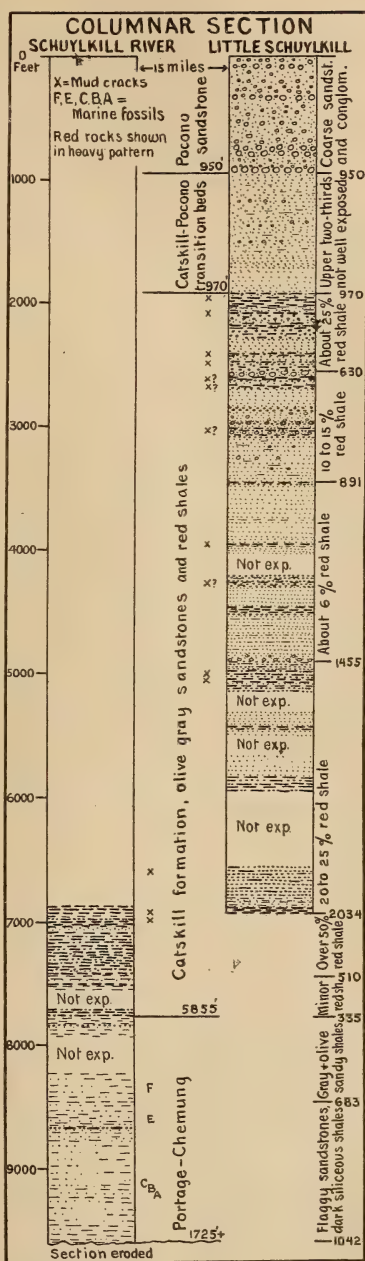


FIG. 2. Columnar sections of Pocono, Catskill, and Portage-Chemung rocks on the Schuylkill and Little Schuylkill Rivers.

which lies below, contained in a calcareous sandstone band. These red shales, on the other hand, show undoubted rain-prints. Mud cracks were found sparingly in loose blocks, and possible rootmarks occur. These contrasted marks of marine and subaerial conditions are here closely related to the change in color from olive shales to red shales and suggest that in Upper Devonian times the climate of this region was such that the contrast in color happens to offer a criterion for separating rather sharply the subaqueous and subaerial phases of sedimentation.

Of the Catskill section only some general notes need be made to supplement the details given in the table. It is to be observed that the lower portion, about 2900 feet thick, is more argillaceous and less resistant to erosion. The middle portion, about 2300 feet thick, consists of resistant gray sandstones with some conglomerate and but a minor amount of red shale. The upper 750 feet have sufficient red shale to permit, in connection with the vertical attitude of the strata, the undermining of the hard sandstone beds and produces a saddle in the Pocono-Catskill mountain crest. In this upper portion is the sharpest and most frequent oscillation from gray sandstone to red shale conditions, and owing to the partial protection from erosion given by the sandstones, the most favorable portion in which to study the bedding character of the shales.

Above the last important red shale and red sandstone are 970 feet of gray and olive sandstones, moderately resistant and not yielding good outcrops on this section. The sandstone is of the Catskill type rather than that of the coarser and harder Pocono. They may therefore be put as transition beds, but their affinities are with the lower more than with the upper formation.

The Pocono here is a much coarser and cleaner grit and gravel formation than in its usual development in Pennsylvania and indicates a nearer relation to the source of the material.

The shales of the Catskill as seen in this section are a bright "freight car" red; the more siliceous red sandstones are, strictly speaking, maroon rather than red. The gray sandstones, if argillaceous, weather to a yellow, showing that they contained iron oxide but in a ferrous state. The purer sandstones, olive-colored on fresh fracture, weather to a grayish white. These relations show there was a tendency toward deoxidation during the formation of the beds of sand, of oxidation during the deposition of the Catskill muds. Where the clay and iron oxide were sparing in quantity, the deoxidation was effective. The conditions which accompanied the deposition of clay and iron oxide also permitted oxidation to dominate over deoxidation. A gray or olive sandstone member is commonly sharply delimited at bottom, but at the top grades first into maroon argilla-

aceous sandstone, and this in turn into red sandy shale. In the sandstones the bedding is usually smooth and even but with considerable oblique lamination. The shales commonly crumble rapidly to a hackly rubbish without relation to bedding planes. In these respects the sandstones and shales conform to the normal widespread character of the Catskill formation.

To turn to the evidences of subaerial origin, for which the section was especially investigated, it is to be noted that mud-cracks or rainprints were found at intervals throughout the entire section, always in horizons of red shales. The section was in fact chosen for study because the beds from top to bottom are here best exposed in detail of any which the writer has seen. In the bulk of the red shales the uniformity of the material, the absence of bedding planes, and the rapidity of weathering prevent the detection of subaerial exposure even if such was the condition of origin, but even in such beds a number of mud-crack patterns were detected. It is where well-bedded shales are interstratified with sandstones, however, that the opportunities for the detection of mud cracks and rainprints are the best. This feature of the stratigraphy as noted applies especially to the upper 750 feet. In all of the mud-cracks of the Catskill the filling was a mud of nearly the same quality as the cracked stratum and the result is usually a shadowy pattern, chiefly visible through a duller luster of the fillings. In rare cases the filling, however, has become deoxidized and shows as a yellow pattern on the red shale. The shale surfaces are flat, the polygons not being concave upward as is commonly the case in the Mauch Chunk and Newark shales. On a part of the mud-cracked surfaces the pattern is obvious to the casual observer, but in more than half it requires careful search and observation to find the evidences and make certain that the irregularities are not mere weathering simulation of mud-crack structures. In this respect the Catskill is much more difficult to study than certain formations in which mud-cracks are a conspicuous feature.

THE CATSKILL ON THE POTOMAC RIVER.

The Catskill appears at the surface on the flanks of successive folds in western Maryland and is described in the geologic reports of that region. From the southeasternmost exposure of Upper Devonian rocks in the Hancock quadrangle of Maryland to the northwestern in the Uniontown quadrangle of Pennsylvania is a distance of about 80 miles across the strike. Having discussed the character in the Schnylkill River section it is desirable to compare it with these localities farther south and west toward the open Chemung sea.

On the eastern side, in the Hancock quadrangle, according to Stose and Schwartz, the Catskill attains a thickness of about 3800 feet. Fifteen miles west, in the Pawpaw quadrangle, its thickness is about 2000 feet, a diminution of more than a hundred feet to the mile. Below this are some 500 feet of beds separately mapped and transitional into the Jennings formation, 4000 to 4800 feet thick. Some 50 miles farther west, G. C. Martin reports the Catskill as 1200 to 1400 feet thick. Only the upper part of the Jennings is exposed here, but in the columnar section it is estimated at 3500 feet in thickness. In the Uniontown quadrangle, 20 miles northwest of the last locality, M. R. Campbell reports that fossiliferous green shales of Chemung age directly underlie the Pocono sandstone. But beginning about 700 feet below the Pocono sandstone, wells have penetrated about 150 feet of red shale. In character the rocks of the Maryland sections are more argillaceous than in Schuylkill County, Pennsylvania, the great thicknesses of olive sandstones of the latter region apparently being replaced by red argillaceous sandstones and red shales. Cross-bedding and ripple marking are common. Stose and Schwartz mention furthermore in the Pawpaw-Hancock folio in 1912 the presence of mud-cracks.

For discussions of the conditions of origin it is important to determine to what extent these marks of subaerial exposure extend southwestward from eastern Pennsylvania and are coincident with the Catskill phase of sedimentation. For this purpose the writer in 1908 studied the section between Frostburg and Cumberland, Maryland, longitude 78° 51' W. This is forty miles west of the eastern outcrop in Maryland, fully sixty miles west of the strike of the Schuylkill River sections, and 160 to 170 miles distant from the latter in a southwest by west direction.

Ascending through the Upper Devonian section, the olive shales are observed to give place to red shales of the Catskill type, some thin layers of olive shale and gray sandstone being interstratified near the base with the red shales. Gradations into argillaceous red sandstones are common. Twenty-five feet above the top of the olive shales* well-defined mud-cracked surfaces were noted and continued to appear through about 140 feet of beds. The polygons range from three to twelve inches in diameter on different surfaces, the fillings from one-fourth to one-half inch across, and differing from the polygons chiefly in luster. No concavity of the polygonal plates is observed,

*The olive shales stop about fifty feet southeast of the east portal of the tunnel of the Cumberland and Pennsylvania Railroad. The tunnel is cut through red shale and sandstone and its waste offered a good opportunity for the study of the basal Catskill.

such as is common in the Mauch Chunk and Newark formations. On a number of the surfaces the larger patterns of cracks are gray-green, contrasting strongly with the red polygons. On one of these the smaller secondary cracks on the same surface were red, contrasting with the gray-green of the larger cracks. One of these mud-cracked surfaces is shown in fig. 3, taken close to the bottom of the red shale.

FIG. 3.

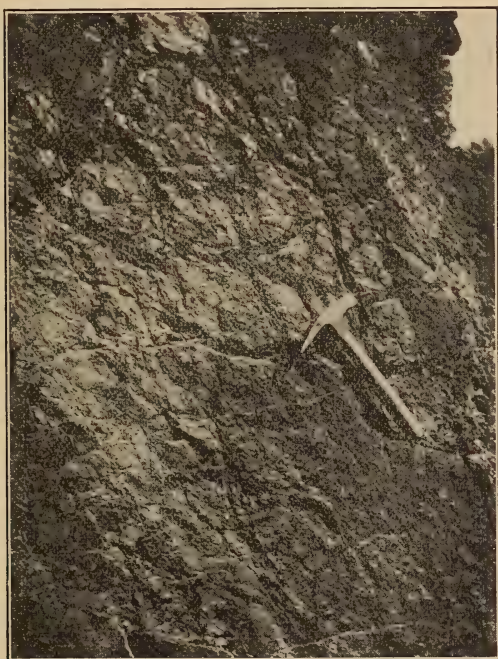


FIG. 3. Mud cracks in the lower Catskill between Cumberland and Frostburg, Maryland. The cracks are filled with green sand in a red shale. Photo taken July 1, 1908.

Some impressions of vegetation occur and measure up to five inches in width, but most of them are of small fragments. In the waste from the tunnel were found slabs showing current marks, rainprints, and rootmarks. A drawing of a specimen of rootmarks is shown in figure 4. Thus in this section, as on the Schuylkill River, the close relation is seen between the marks of subaerial exposure and the change of color from olive to red, but the conditions involving deoxidation and oxidation

are more nearly balanced in this transition zone than in the true Catskill above, as shown by the green filling of some of the mud-cracked red shales and the tendency to variegation in color in these basal beds. The upper Catskill in this section is not favorably exposed for study. The shales are sandy and have crumbled in weathering until the original characters have become destroyed, but the more significant base was still at

FIG. 4.

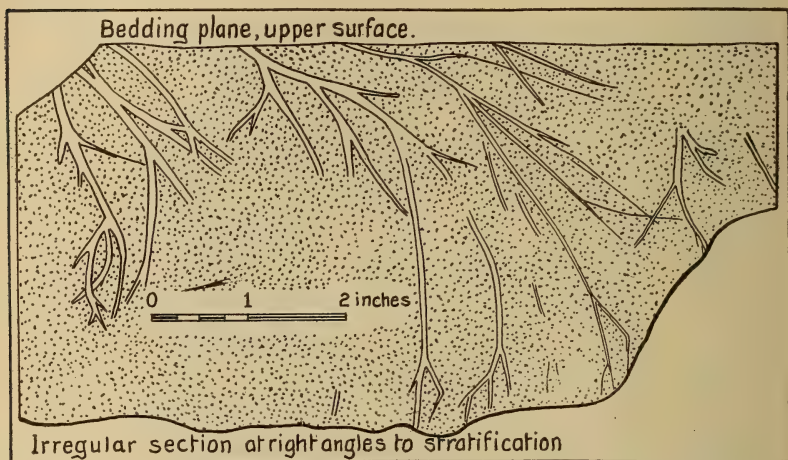


FIG. 4. Rootmarks in red argillaceous sandstone. Lower Catskill, near Frostburg, Maryland. The fracture surface which exposes these rootlets is irregular but roughly at right angles to the bedding plane.

this time well exposed by the tunneling and cutting for the railroad.

These observations from Pennsylvania to Maryland show the widespread development of the marks of subaerial exposure through the red beds of the Catskill. They are not marginal or shoreward developments within the Catskill, but may occur as widely as the red rocks themselves. It required special characters of beds, however, to clearly preserve the cracks in the original deposition and fresh exposures are necessary for their observation. The red color is, however, something which is not readily destroyed, being inherited even in the soil, and in this particular formation, in widely separated localities, it is seen to mark the disappearance of marine faunas in gray or olive shales and the appearance of the marks of subaerial exposure. Following the criteria previously discussed, the red shales mark, in the Upper Devonian physiography of the Appalachian region, the subaerial plain of a far-reaching delta.

RECONSTRUCTION OF PHYSIOGRAPHY AND CLIMATE OF THE
CATSKILL DELTA.*Comparison of the Catskill and Skunnemunk with the Siwalik formation.*

A formation strikingly suggestive in connection with the present subject, and one in regard to which the interpretation of subaerial origin has found general acceptance because of the clear indication of the fossil record, is the Siwalik formation of the sub-Himalayas. In order to show the similarities to the Oneonta, Catskill, and Skunnemunk formations, a short description of the Siwalik will be given. These are Neocene deposits upwards of fifteen thousand feet in thickness, skirting the southern side of the Himalayas. They were laid down as alluvial outwash from the rising mountains and have become exposed through being themselves upturned and eroded in the latest movements. Medlicott and Blanford describe the Siwalik formations as follows:

“Sandstone immensely preponderates in the Sub-Himalayan deposits, and is of a very persistent type from end to end of the region and from top to bottom of the series. Its commonest form is undistinguishable from the rock of corresponding age known as Mollasse in the Alps, of a clear pepper and salt grey, sharp and fine in grain, generally soft, and in very massive beds. The whole Middle and Lower Siwaliks are formed of this rock, with occasional thick beds of red clay and very rare thin, discontinuous bands and nodules of earthy limestone, the sandstone itself being sometimes calcareous, and thus cemented into hard nodular masses. In the Sirmur group generally (below the Siwalik group), and locally in the Lower Siwaliks, the sandstone is thoroughly indurated and often of a purple tint, while retaining the distinctive aspect. In the Upper Siwaliks conglomerates prevail largely; they are often made up of the coarsest shingle, precisely like that in the beds of the great Himalayan torrents. Brown clays occur often with the conglomerate, and sometimes almost entirely replace it. This clay, even when tilted to the vertical, is undistinguishable in hand specimens from that of the recent plains deposit; and no doubt it was formed in a similar manner, as alluvium. The sandstone, too, of this zone, is exactly like the sand forming the banks of the great rivers, but in a more or less consolidated condition. Thus it was suggestive, and not altogether misleading, to say that the Siwaliks were formed of an upraised portion of the plains of India.

“The fresh-water origin of the Siwalik formation seems almost as indisputable as the marine origin of the Subáthu beds; yet, until lately (1879), it has been usual to consider the Siwaliks marine. The notion was probably a relic of the opinion that a water basin was an essential condition of the extensive accumula-

tion of deposits, and that a sea margin would be required for such a great spread of shingle as that of the Siwalik conglomerates. The same opinion, on the same grounds, has been extended to the plains deposits themselves.

"The continued experience that the fossil remains in these Tertiary strata are exclusively of land or fresh-water organisms, made this view untenable; and in time it came to be realized that the deposits themselves bear out the same opinion; the mountain torrents are now in many cases engaged in laying down great banks of shingle at the margin of the plains, just like the Siwalik conglomerates; and the thick sandstones and sandy clays of the Tertiary series are of just the same type of form and composition as the actual deposits of the great rivers.

"Beds of this character alternate with the upper beds of the Subáthu group; so it seems probable that from early Tertiary times the sea has been excluded from the Sub-Himalayan region, and that the whole of the Sub-Himalayan deposits, above the Subáthu group, are fresh-water and fluviatile, and formed on the surface of the land. They are in fact, subaerial formations, like the river alluvium and bhabar deposits of the present day.*

Speaking of these formations as they occur in the Salt Range in the Punjab, Wynne makes the following statements:

"Everywhere from one end of the range to the other, and always on its northern and eastern aspects, the uppermost rocks of the Salt Range series are innumerable alternations of grey or greenish sandstones, of no great hardness, with red or light-brownish orange clays, more rarely with conglomerates, but frequently with harder fine-grained sandy beds of peculiar concretionary pseudo-conglomeratic structure . . . The alternating bands of sandstone and clay are from seventy to a hundred and twenty feet in thickness, being very frequently about a hundred feet each, but some zones are much thicker."†

It is the middle Siwalik which especially shows the association of gray or green sandstones and red clays. All parts are associated with the bones of mammals and fresh-water reptiles. It is seen from this description that such combinations of red clays and gray or green sandstones are features of fluviatile deposition under certain intermediate climatic conditions.

Conditions of Origin of the Several Appalachian Formations.

The marks of subaerial exposure in the Oneonta-Catskill beds have been shown to be an integral feature of the formation, were made without relation to a shore, and contrast sharply with the stratigraphic characters of the Chemung. These features constitute the strongest test stated under the subject of criteria. The general descriptions serve further to emphasize

* A Manual of the Geology of India, ii, pp. 524-526, 1879.

† Memoirs of the Geological Survey of India, xiv, p. 108, 1878.

the many distinctions between the subaerial and subaqueous deposits. The conclusion may be accepted, therefore, without further argument, that delta conditions prevailed and that the Catskill formation is made of the deposits on the subaerial plain. This section consequently will be devoted to an analysis of special features of the delta as derived from the study of the formation.

The Portage and Chemung are seen to be the shallow sea equivalents of the Oneonta and Catskill, a subaqueous topset plain. The Skunnemunk conglomerate is a downfolded remnant of a piedmont alluvial gravel plain which lay between the flat delta surface and the mountains. The Pocono sandstone, into which the Catskill passes by transition, is seen to be divided into two phases,—a marine phase in western Pennsylvania and Ohio, a fluviatile phase in eastern Pennsylvania. In the Pocono, the sharp delimitation of the two phases is obscure but between the Catskill and Chemung the color contrast draws the dividing line separating the subaerial and subaqueous topset beds. The margin of the delta no doubt held lagoons, varying from brackish to fresh water; so that marine fossils should be somewhat more restricted in their range than the gray and olive shales.

The delta began its existence when the rivers were given a sufficient load of detritus to stem back the planing erosion of the sea. So far as known, this was near the close of the middle Devonian. For a time the rivers gained ground and the Oneonta formation was built out. But at the close of Portage time the sea gained a temporary ascendancy and advanced nearly to the eastern limit of the present Catskill Mountains. During the Chemung, however, it was again gradually dammed back and retreated to western Pennsylvania, the oscillating shore line being marked by the transition zone of sediments. Back from the margin the uniformity of the red shale shows that the delta surface was sufficiently well drained to prevent the formation of extensive swamps, such as exist over the lower and flatter lands of the Mississippi and the Ganges delta. This was doubtless in part due to the climatic factor, but also in part owing to the relatively short courses of the rivers and consequently a steeper gradient to the delta plain. The axis of the geosyncline, the line of maximum subsidence, was near the ancient mountains. The streams had to deposit most of their burden over this zone and had but little left with which to push the ocean waters farther back. The western part of the geosyncline was in consequence mostly marine, passing out into the open shallow sea; the eastern part was mostly maintained as land, passing through a piedmont plain to the mountains.

The Catskill formation consists typically of alternating mem-

bers of gray sandstone and red shale. In certain regions and at certain horizons the one becomes the dominant facies, in other regions and times the other dominates the formation. Under the view that the whole constitutes a delta the alternations of minor shale and sandstone members is to be ascribed to the lateral shifting of distributaries, the red shales representing flood plain areas temporarily removed from the presence of currents. The delta was far from the regions of erosion, with the result that the same kind of material was brought year after year to each locality subject to change only as the distributaries shifted. The oxidation of the shales shows that the soil was drained and aerated for considerable periods yearly. The stratification planes in the muds, initially poor because of uniformity of material, were customarily more or less obliterated. There are several subaerial agencies which result in this where the rate of sedimentation is sufficiently slow.—Worms and other burrowing forms carry on a vertical mixing of the soil. The growth and decay of roots tends in some degree to the same end. But a very effective agent for vertical mixing in climates subject to periodic dryness is mud-cracking, where the binding action of roots does not prevent it. Each wet season fills the cracks largely by slumping in from the top, and each dry season reopens them. The evidence seems to show that in Catskill times all of these processes were in operation, but the writer, from observations on present mud flats, is inclined to ascribe a chief place to the effect of mud-cracking.

The uniformity in the character of the delta from northeast to southwest, its development marginal to the uplands, and the somewhat rapid gradation from gravel to sand and clay on leaving the mountains suggests the presence of a number of comparatively short streams which built flat coalescing fans rather than the debouchement of one or two great continental rivers. The form of the plain was somewhat similar to that plain of Tertiary alluvium which faces the Rocky Mountains, and was built by overloaded rivers in a region of semi-arid climate. Here the rivers flow out at gradients of near 10 feet per mile and fall to 7 to 5 feet per mile at a distance of some hundreds of miles.

An average gradient of 5 feet per mile for the Catskill plain over a width, at the close of the Devonian, of from 80 to 100 miles would appear therefore to be a reasonable estimate. Toward the mountains the slope of the piedmont gravel plain doubtless steepened, perhaps to 15 or 20 feet per mile in the case of large streams, even higher for streams of lesser volume.

Subsidence of the geosyncline under this plain, depressing the grade of the rivers, would result in alluvial sedimentation at elevations of several hundred feet above the sea and at indefi-

nite distances from it. This suggests a very different conception from that of brackish water sedimentation or deposits in partially enclosed standing waters such as has usually been assigned as the cause of the Catskill facies.

The interstratification and intermixture of sand and clay together with minor quantities of muscovite and feldspar indicates that the material was derived directly from the rocks and was not the reworked sands from a coastal plain. The great thickness and coarseness of the Skunnemunk conglomerates implies land of high relief, and rivers of strong grade. The large volume of the finer materials deposited farther west is equally testimony of an even larger volume of the sources of supply. The Skunnemunk conglomerate has been partly destroyed by erosion, but 2,500 feet of coarse gravel still remain. Only rarely, however, during Catskill times, did gravel reach the main area in New York and Pennsylvania, 25 miles farther west. A condition existed, therefore, which prevented the sweeping outwards of gravels. When a river reaches a part of its course which is below grade it must deposit its coarser burden in order to carry the finer material through. This suggests that subsidence was rapid, and continued not only in the zone where the thick Catskill beds still exist, but over an eastern border which in the later folding has been uplifted and subjected to erosion, save for the single narrow syncline within the pre-Cambrian gneisses which still holds the Skunnemunk conglomerate. Another factor which may have a bearing is,—that in a dry climate rivers which flow from high mountains tend to shrink in volume on reaching the plains and therefore quickly drop their coarser waste. This steepens the gradient but cannot continue indefinitely without progressive elevation of the mountains, or subsidence of the plain.

Beyond the shore of the delta plain were the waters of a shallow sea, whose bottom was probably affected by waves throughout. The upbuilding then was wholly by the deposit of topset beds,* the sediment being spread by rivers on the landward side; by waves on the side of the sea. The delta was not built out by means of foreset beds such as are seen where small deltas grow out into relatively deep water of constant level.

The several formations are thus seen to be the members of a larger structure—a delta system, which is marked by the existence of subaerial aggradation but which is linked to and embraces the synchronous marine formations, the latter forming the foundation over which the subaerial deposits are commonly extended.

* Following the classification given on pp. 385-387 in the paper by the writer "Criteria for the recognition of ancient delta deposits." *Geol. Soc. Am., Bull.* xxiii, pp. 377-446, 1912.

Inferences Regarding Climate.

The relations between climate and terrestrial deposits have been discussed by the writer elsewhere,* and the conclusions reached in that paper will be utilized as a point of departure in this.

The idea, which may be traced to Russell, that red in sediments is a mark of derivation from a deeply decayed regolith, has widely pervaded American geological literature and competes with the European view that red is significant of ancient aridity. The first interpretation has been adopted by Willis in his reconstruction of Upper Devonian times; the second has been utilized by a number of British and Continental geologists who have written of the Devonian deserts of Europe as recorded by the Old Red Sandstone. The redness of the Devonian rocks of northwestern Europe, made of waste from northwestern lands now largely under the sea, has led Walther to name this now dismembered continent, "the Old Red Northland." But the present writer has argued elsewhere† at length that redness in rocks is not necessarily evidence of redness of the original sediment; the latter may have been red, brown, yellow, or yellowish gray. All that is necessary is the presence of ferric oxide, hydrous or anhydrous. If in the course of geologic time the water is driven out, the coloring matter will necessarily become red. Furthermore, certain red rock formations have originated under conditions which show that high rainfall with seasonal dryness is competent to produce this color as well as aridity. Other formations show that rapid mechanical erosion, with imperfect decay, may be associated with redness as well as the contrary condition of deep decay over a land of low relief. In fact the latter is probably the least common condition associated with thick formations of red sandstone and shale. To cite a few examples which bear out these statements of varied conditions of origin: It is seen that the Amazon and the Congo are now depositing red marine muds off their mouths from climatic regions marked by tropic heat and seasonal rainfall. The Potomac formations of the Atlantic Coastal Plain, of Comanchean age, are marked by brilliant red and orange beds associated with blue and white clays and abundant plant remains. The Newark formations of Triassic age are red to brown sandstones and shales with much feldspar and muscovite showing imperfect decomposition. Coal beds occur in this terrane in Virginia and North Carolina. The Siwalik formations of India contain a fossil record which disproves aridity and accumulated under physiographic con-

* Jour. Geol., xvi, 1908, pp. 159-190, 255-295, 363-384.

† The Climatic Significance of Color. Jour. Geol., xvi, 1908, pp. 285-294.

ditions which disprove derivation from the deep regolith of a mature topography. The red clays of the Siwalik were on the contrary laid down under comparatively similar conditions to those which now give rise to the lighter-colored alluvium of the Indo-Gangetic flood plain, or the yellow floods of the Chinese rivers, or the muddy waters of the American Missouri. Lastly, the frequent association of red beds with salt and gypsum shows especially in the Permian that redness frequently accompanies aridity.

The determination of the climatic conditions under which a terrestrial formation was laid down must therefore depend upon the analysis of a combination of characters, and this becomes especially necessary when the marks of climatic extremes, as glacial deposits on the one hand, or evaporation deposits on the other, are absent from the formation.

Turning to those features of the Upper Devonian delta which are significant as to climate, the most broadly distinctive is the characteristic redness of the Catskill shales, and the gray or green colors of the cleaner sandstone members. In this the Catskill resembles the Siwalik formation and could have been deposited under similar physiographic and climatic conditions to those prevailing in northern India in Neocene times, rapid erosion in high mountains, deposition on river plains marked by warmth and seasonal rainfall.

The red shales are associated especially with mud-cracking, and by contrast with the gray and olive shales of the Chemung show that the oxidation was due to periodic drying of the flood plain and aeration of the soil. The lack of oxidation of the iron in the sandstones, in spite of its lesser quantity, suggests that more abundant ground-waters in the sands may have kept out the air and permitted the organic matter to accomplish its effects, or perhaps that here the ratio of organic matter was in excess of the ferric oxide. The oxidizing conditions in general were nearly balanced by those of deoxidation as seen by the contrast in color of the shales deposited under permanent water and the yellow or green pattern occasionally observed in the filling of mud-cracks.

A few rare carbonaceous streaks have been observed in the Catskill and the plant impressions are in places found in deoxidized shales. Coaly and pyritiferous plant fossils are also preserved in some of the olive sandstones. In other strata mere lustrous red streaks show the marks of vegetation, implying that the oxidation of the organic matter was commonly by the free oxygen of the air, since the destruction of the organic matter did not deoxidize the adjacent ferric oxide.

The climatic conditions of the Upper Devonian were equable and widespread as seen by the similarity of deposits and of

plant types over wide ranges of latitude and longitude. The intermediate character of the climate in regard to rainfall is indicated by the almost universal absence of either carbon or evaporation deposits. Hence there was sufficient dryness and oxidation to destroy such organic matter as developed over the river flood plains, but sufficient rainfall in excess of evaporation to prevent in the marginal lagoons the concentration of evaporation products. With equable rainfall throughout the year this balance would be more delicate to maintain; but with seasonal rainfall and dryness, the typical climate of the present tropics, a wide range may exist in the relative length of the seasons and amount of rainfall and still permit the drying of the soil at one season, the washing out of evaporation deposits at another.

The climate of the Catskill delta has thus been narrowed down to two types. First, semi-aridity, characterized by a scanty rainfall throughout the year, preventing the luxuriant growth of vegetation at any time; or, second and more probable, a climate of seasonal rainfall, probably in the growing season, since this favors herbaceous rather than arboreal vegetation. Semi-aridity gives rise to the pampas of Argentina and the staked plains of Texas; abundant but seasonal rainfall to the llano of the Orinoco, the savannas of tropical Africa and the monsoon tracts in India. A rather warm climate is suggested, since such favors rapid drying and oxidation of the soil.

The climatic conditions which have been inferred stand between those which gave rise to the carbonaceous muds and dark sands of the Middle Devonian, even where these hold terrestrial deposits as in the Bellvale flags; and the red sandstones of the upper Mississippian with the gypsum deposits of Nova Scotia and Virginia, and the briny strata of Michigan. The climatic movement at the close of the Middle Devonian was not severe, but was sufficient to result in effective oxidation of alluvial muds where previously this had not taken place. With the beginning of the Mississippian a greater climatic instability manifested itself, conditions favorable to the development of coal marking the early Mississippian, but not unmixed with evidences of oxidation and evaporation occasionally more pronounced than in Devonian times. Finally, in later Mississippian times, a period of considerable aridity set in.

Having made this analysis of climatic conditions from the physical and chemical characteristics of the strata, it is of interest to note the conclusions which have been derived regarding Upper Devonian climates by the students of fossil vegetation.

In a study of the upper Paleozoic floras, their succession and range, David White states

"The first Paleozoic land flora sufficiently known to make it eligible to the series of correlation discussions is that of the Middle Devonian. This flora, whose apparent meagerness is perhaps due mostly to meagerness of information, is of strange and forbidding aspect. . . .

"Evolution of forms and the advent of new types mark the Upper Devonian flora, which bears no evidence of any great climatic separation from the preceding. . . .

"The Devonian woods present no annual rings to bear evidence of seasonal changes in temperature or intervals of prolonged drought. . . .

"The step from the Upper Devonian flora to that of the Mississippian ('Lower Carboniferous') is marked by a floral contrast which, in some regions, is unexpectedly sharp through the warping of the Devonian floor to form the new Carboniferous synclines, and the contraction of the seas naturally premise distinct climatic as well as other environmental changes. . . .

"In this connection it may be noted that, either on account of land or marine barriers, or because the climatic conditions throughout the northern hemisphere may at the outset have been less uniform than in the preceding epoch, the different areas exhibit more or less distinct local floral differences."*

G. W. Matthew states

"The conditions of climate which would seem to have best suited the Devonian types was that of a dry and cool atmosphere, broken annually by a short period of rains, when the short and scanty vegetation made a rapid growth. Such conditions at least would best accord with the prevalence of xerophytic forms like the Psilophyta and the small leaved *Lepidodendra*, and the rarity of the *Equisetinae*. Broad leaved plants like the *Cordaitea* are rare in the Devonian vegetation and the filicoid plants are mostly of the genus *Archaeopteris*. The plants that did prevail are mostly recorded as having had rhizomes or fleshy root stalks, and in these could have stored up the nourishment which enabled them to throw out a vigorous growth at that time of the year when the season of expansion arrived."†

The flora of the Little River Group, concerning which Matthew makes these remarks, is regarded by David White as of post-Devonian age. This may be accepted, but the types of vegetation are such as mark also the Upper Devonian and the same inferences as to climate would apply.

The physical and organic evidences must supplement each other and where there is an apparent conflict some adjustment of views must be made. In general there is no essential discordance of the two lines of evidence, but the presence of

* Jour. Geol., xvii, pp. 322-324.

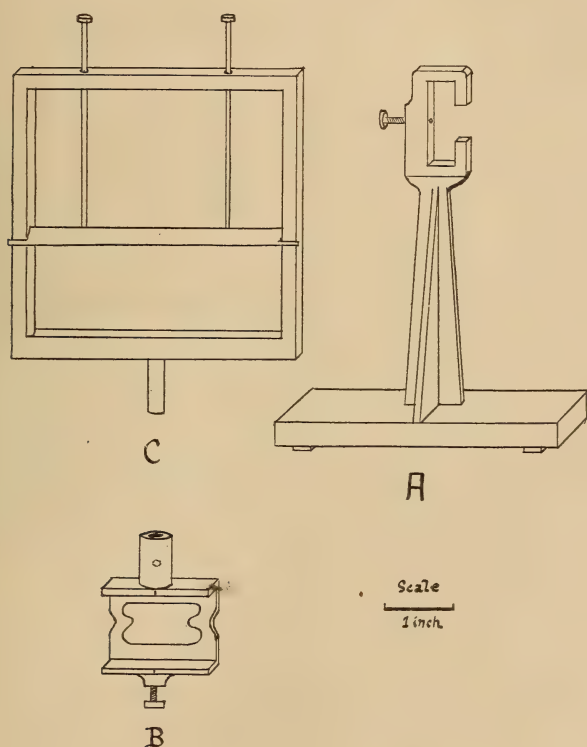
† Review of the Flora of the Little River Group, No. III, Trans. Royal Soc. Can., Third Series 1910, vol. iv, section iv, p. 8, 1911.

seasonal dryness though not aridity, and the absence of annual rings, may seem somewhat contradictory. If the adjustment be sought by modifying the conclusions in regard to climate, a condition of perennial intermittent rainfall may be substituted for seasonal rains. Such a shorter rhythm, measured by days or weeks rather than by seasons, may be so adjusted as to give opportunity for drying and oxidation, but without stoppage of vegetable growth. A delicately balanced condition such as this would, however, be expected to pass in some regions, as previously noted, into markedly humid conditions, or in others into marked aridity, and give rise to a climatic variety of which there is not evidence in the Devonian.

If the adjustment be sought within the limits of vegetal adaptation, two suggestions may be offered. First, is it possible that perennial plants of that time may have possessed such a nature as not to have recorded by rings the stoppage of growth? This is a question for paleobotanists to answer. The most probable explanation, however, to the writer seems to lie in the proposition that at that time perennial and arboreal vegetation was restricted to regions of perpetually available ground-water. In a climate without freezing winters it was thus not affected by the coming and going of rains. This view receives some support, so far as the writer has observed, from the distribution of the plant fossils. The impressions of tree trunks and of strap-like leaves on the whole are rare, but where they do occur are found in decolorized shales or sandstones. Not infrequently coaly streaks mark their presence. These may be regarded as the deposits of swamps or marginal to river channels. The red shales, on the other hand, are doubtless the deposits of flood plains, dried out during a part of the year, air taking the place of water in the soil. In these deposits indistinct tendril-like markings are not uncommon, traceable only by faint changes in luster and texture, not by the presence of deoxidation. They are seldom as definite as in the example shown in fig. 4, but suggest either the thread-like burrows of small worms, or the small rootlets of an herbaceous vegetation. Such an areal distribution of arboreal and herbaceous vegetation in alluvial regions is that in fact which tends to take place to-day within those parts of the tropics marked by pronounced dry seasons, but the present differentiation and adaptation of trees to a wide range of environments apparently makes the environmental control less compulsory than in Paleozoic times. Then the local combination of perpetual ground-water and perpetual warmth may have stimulated in the rivalry for sunlight the striving upward of sporophytes, creating the first of trees and the truly primeval forest.

ART. XLI.—*An Optical Bench for Elementary Work*; by
H. W. FARWELL.

THE ordinary type of optical bench found in elementary laboratories usually consists of a meter stick supported in wooden holders, with fittings for lenses, etc., of sheet metal bent to slide on the meter stick. These fittings offer little opportunity for small adjustments which are frequently necessary for the



success of the work. In addition, frequent bending of the slides to make them fit the meter stick causes a large mortality in fittings. To make our elementary work in light more successful the type of bench described below has been devised.

The meter stick as before is the base of the apparatus, (though we are now using sticks two meters long). This is supported by two rather heavy supports, A, shown in the

diagram. This raises the stick to a convenient height above the table, where it is ready to receive the fittings. These are all attached to the stick by means of the clamp, B, the upper part of which is drilled to receive any $\frac{1}{4}$ -inch stock. The face of the clamp is marked in machining with a line opposite the axis of the $\frac{1}{4}$ -inch hole, so that the error in locating the index is made very small. The clamp is entirely open on the front that it may be machined easily and that it may be quickly set on any part of the bar. It was expected that there might be some trouble on account of the ease with which the clamps might "fall" off the stick, but in the two years in which the apparatus has been used there has been practically no difficulty.

The design of a lens holder required more attention than all the rest, as it was desirable that a single piece should serve to hold, firmly and properly centered, any form of lens, mirror or screen, and at the same time permit quick adjustment or exchange. The frame C meets all the requirements and has proved very satisfactory. The $\frac{1}{4}$ -inch rod below fits into the clamp on the bar. The lower part of the frame is milled with a V groove, the full width of the frame. The movable part is made from right-angled brass stock, slotted at the ends.

One great advantage of the apparatus is the ease with which a frame, holding, say, a ground-glass screen, can be replaced in the same position by a $\frac{1}{4}$ -inch rod bearing a pin to locate an image by the parallax method.

The supports, clamps, and frames are all of cast iron, and are of such form that they are easily machined. Experience has proved that they are not too clumsy for the work in hand, and that they are easily adapted to variations in method in the standard experiments.

Columbia University,
April 19, 1913.

ART. XLII.—*Volcanic Research at Kilauea in the Summer of 1911*; by FRANK A. PERRET. With a Report by Dr. ALBERT BRUN on the Material taken directly from "Old Faithful."

To readers of the six preceding papers of the present series*—devoted specifically to a discussion of the various Kilauean phenomena, products and formations—it will have been evident that, by reason of the necessary concentration upon each particular subject, no detailed reference to the research work, itself, could therein be made. This must be the writer's excuse for venturing upon a seventh paper, which, free from such restrictions, may be devoted to a brief exposition of the origin and aim of the expedition, of some of the research work accomplished and, finally, of data secured and resulting from subsequent investigation of original material collected.

The expedition—and with it the initiation of regular and continuous observations at Kilauea—was due to the initiative of Prof. T. A. Jaggar, Jr., geologist of the Massachusetts Institute of Technology, who, during a previous visit to Hawaii, had become impressed with the opportunity which Kilauea, above all other volcanoes, offers for direct research work, and determined to organize, if possible, a demonstration of its feasibility. To this end, negotiations were entered upon between the Institute and residents of the islands, a promise of coöperation by the Carnegie Geophysical Laboratory was obtained, and a set of cables and electric thermometers, for spanning the crater and for immersion in the liquid lava, were prepared. Nevertheless, for various reasons, years passed without accomplishment and, at the beginning of 1911, the entire project stood to expire of inanition.

At this stage Prof. Jaggar, finding himself unable to assume the charge, made a personal appeal to the writer to head the expedition to Kilauea in the hope of making a demonstration of such practical utility as should result in the establishment of a permanent institution on the spot, and promising to take up the work, himself, at a later date. Although very loath to interrupt, even temporarily, his work in Italy,† the writer considered the foundation of such a work in his own country of foremost importance, and it was thus that, in company with Dr. E. S. Shepherd, of the Carnegie Laboratory, he arrived at the islands in June and commenced those observations and studies

*This Journal, xxxv, 139, 273, 337, 469, 611; xxxvi, 151.

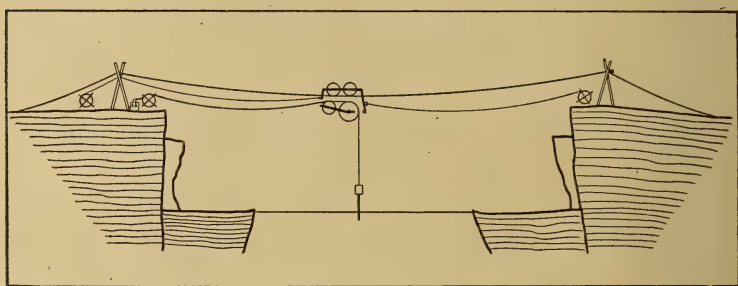
† After having lived through the Etna eruption of 1910, all the phases of which were observed and photographed, the still more important outbreak of 1911 was thus missed, leaving a gap which can never be filled.

which have been briefly considered in the preceding papers of the series.

The project may, therefore, be said to have been founded by the Institute of Technology and the people of Hawaii through the initiative of Prof. Jaggard; with the coöperation of the Carnegie Laboratory, as represented by Dr. Shepherd; and carried into effect by the Volcanic Research Society, in the person of the present writer.

It is but fair to state that the financial means of the expedition were extremely limited and that, had it not been for the hearty disposition of the residents, one and all, to aid and facilitate the work by every means in their power, the results would have been very different. Noted for hospitality and good will, their attitude toward the workers was beyond all

FIG. 1.



praise and the writer takes this opportunity of expressing his grateful appreciation of all that was done.

A difficulty, graver than the financial one, lay in the changed volcanic conditions at this time as compared with Prof. Jaggard's visit in 1909. Then, a complete "black ledge" stood within the walls of Halemaumau forming an accessible platform at no great distance from the lake of lava over which it was proposed to stretch the cables, but, by 1911, this was, for all practical purposes, non-existent, the few remaining sectors being quite unsuitable for supports and anchorages, as will have been evident from a perusal of the paper on "Subsidence Phenomena."* It became necessary, therefore, to work from the top of Halemaumau, and this increased the magnitude and the difficulty of the operations beyond all anticipation.

From figs. 1 and 2 the reader will obtain some idea of the apparatus erected for the purpose of obtaining temperature measurements of the lake lava and for collecting the material, itself, directly from the lava fountains. In the outline sketch

* This Journal, May, 1913.

it was necessary, for the sake of clearness, to greatly exaggerate the size of the trolley and the height of the A-frames constituting the main cable supports, with the unfortunate result of reducing the apparent dimensions of the crater to an almost ludicrous proportion—properly, the size of the trolley should be less than a tenth of the diameter of its smallest wheel, as drawn, and the height of the A-frames, and their distance from the crater's edge, should be reduced in proportion.

FIG. 2.



FIG. 2. Showing cables, trolley, and winch, at eastern edge of the crater.

A $\frac{3}{8}$ -inch Lidgerwood steel cable with hemp core was employed, the total length between anchorages being 530 M. of which nearly 400 M. was clear span between A-frames. This was stretched to a 5 per cent drop according to recommendation of the engineers,* in which condition the center of the span hung some 56 M., at the beginning, above the surface of the lake, the subsequent sinking of which increased this considerably and added greatly to the difficulty of lowering the instruments.

* For others who may undertake similar experiments the writer would advise a greater drop, not only as lessening the strain but as actually facilitating the sending of the trolley to the center of the span.

AM. JOUR. SCI.—FOURTH SERIES, VOL. XXXVI, No. 215.—NOVEMBER, 1913.

The western anchorage was the projecting tongue of an old lava flow around which the cable was bent and secured with clips, while at the eastern end logs were buried crosswise in a cleft of the lava rock.

A team of horses, with appropriate tackle, was employed for the final stretching of the cable to a 5 per cent drop.

The trolley, shown in fig. 2, ran on this main cable and could be brought to any desired position above the lake by means of two smaller guy cables, pulling in either direction by winches, as shown. An insulated electric cable, running over the lower wheels of the trolley and, also, under the control of a winch, served to lower the instruments into the lake and to maintain the electrical connection with the indicating apparatus "on shore." It was found necessary to support the horizontal portion of this cable at intervals by small pulleys running on the main cable in order that its weight should not prevent the lowering of the instrument—an arrangement which could not well be shown on the diagram.

All was thus ready, but an incident, occurring at this stage of the proceedings, has so important a bearing upon the subsequent experiments that it may well be related here. A kink in one of the smaller cables caused it to break and fall into the lake, where it was quickly fused. Now, the temperature of the Kilauean lava has been quite generally considered to be at least equal to the fusing point of wrought iron, for the reason that rods or wires of that metal, immersed in the lava, were rapidly fused. The lava melted the iron—ergo, it had the heat to do it—no deduction could be more simple, more direct, nor more convincing. And yet, to a practised eye, the degree of incandescence—even in the fountains and in spatter-grottoes where the lava was protected from radiation—indicated a much lower temperature. The fusing of the steel cable would mean, let us say, 1300°C. , but it was impossible to admit such a degree of heat. How, then, explain the fusion of the steel?

The first glance at the fused cable-end showed the metal to have been converted into the *sulphide*, and it was realized that, not thermal action alone, but *chemical activity*, as well, was here involved. The presence of sulphur—revealed by the abundant evolution of SO_2 —had not been considered in planning the experiments, and this incident of the fused cable boded ill for the instruments destined for immersion in the lake.

But another, and broader, consequence results from this demonstration of chemical activity, viz., that all estimates of the temperature of liquid lavas based upon the melting therein of wires or strips of various metals whose fusion points were known, must be considered as having practically no value. As

will be seen later, tubes of nickel, the fusion point of which we may take as being at the least 1450° C., were readily dissolved in this lava, whose temperature could not have approached to within 300° of this.

The first attempts to obtain a temperature measurement were made with resistance coils of fine platinum wire enclosed for protection in concentrically disposed tubes of quartz, nickel and iron, the electrical resistance of the platinum coil varying with its temperature and being read by suitable instruments connected with the shore end of the connecting cable. Needless to say, the metal tubes were several meters in length, and the adjoining portion of the insulated cable was protected by a spiral steel casing.

One of these instruments was successfully lowered into the lake on July 20th, but the electrical connection failed at the moment of immersion and a lava fountain carried away the instrument with all the armored cable. Just before this occurred, however, the spring of the main cable had lifted the instrument, for a moment, quite clear of the lake and it was seen that the metal tube had been fused off at the level of immersion.

Nine days later a second, similar instrument failed, in like manner, to register, and it was evident that this type of thermometer, however useful in the laboratory, was too delicate for the rough conditions of crater activity.*

The third and successful attempt was made on July 31st with a *thermo-electric* couple of platinum and iridio-platinum. This was set up by Dr. Shepherd in a heavy iron tube and the cold end of the element was surrounded by a large iron cylinder filled with water.

It should be said here that, by this time, the conditions at the crater had become exceedingly unfavorable for the continuation of the experiments. The sinking of the lake greatly increased the difficulty of lowering the instruments into contact with the lava, while dense clouds of vapor rendered the lake itself quite invisible from the operating point and made necessary a line of signal-men around each side of the crater for receiving and transmitting previously arranged wig-wag signals from the writer, to whom, alone—perched upon the crag of a sunken ledge, inside the pit—the lake surface and the descending instrument were visible.

In this manner the element was immersed some 30 to 50^{cm} below the surface of the lava, where a thin crust was readily perforated by the descending tube. The shore instrument showed the increasing temperature as the element descended

* The Kilauea lava fountains send tons of heavy liquid to a height of from 6 to 12 meters.

and, when this was immersed, gave, with the correction for the cold-end temperature, 1050°C . The cold-end temperature was taken as being virtually 100°C from the writer's observation of steam issuing strongly from the water jacket (neglecting altitude). The instrument was quickly withdrawn from the lava—its tube already almost gone—and, in a second immersion, was engulfed by a fountain and lost.

The temperature reading thus obtained agrees with the visual estimate of Dr. Shepherd, whose experience in furnace work has given him a special aptitude in this direction. The writer had estimated the fountains at slightly over 1100°C ., and it may be that this difference actually exists between the fountains and the still lava beneath a crust, although it is contrary to all the writer's experience that there should be any very considerable difference of temperature in different parts of a mass of fully liquid lava, even in the case of a long, flowing stream.

It is, at all events, quite obvious that the heat of Kilauean lava has been generally overestimated in the past. "White heat" is a convenient expression, and is a condition easily imagined in contrast with dark surroundings of a warm tint, but a tungsten pocket lamp will quickly dispel the illusion.

Dr. Shepherd, on his second visit to Kilauea, had the privilege of witnessing one of those phenomenal increases of activity which fill the pit from side to side with a lake of boiling lava without a trace of crust, yet the temperature fell short of 1200°C .

A curious observation by the present writer goes far, however, towards explaining the many references to white heat. During the first few nights of his stay at the crater he was, himself, impressed by sudden apparent increases in the temperature of the lava as shown by a change from the golden glow to a whitish incandescence. There being no other indications of greater activity which might account for this phenomenon, he continued to observe the lake and found that, at times, this whiteness appeared in places while the rest of the lava retained its original color. This clearly indicated a cause other than temperature variation, and a little further study resolved the mystery. In the paper on lava fountains reference was made to the gases which, on issuing from the lava, burn in the air with a visible flame and the production of a cloud of the burnt vapors. These vapors, although transparent, have, by reflected daylight, a bluish tint, but when viewed by transmitted light are of a yellowish brown or reddish brown color, according to their density—a color and a quality which is highly absorptive of those orange and yellow rays so abundant in the golden-hued lava. Seen at night through a veil of this transparent vapor, the glowing liquid, although somewhat

less brilliant, appears of a whitish incandescence, giving the impression of higher temperature.

From all the foregoing remarks it should not be inferred that the writer is casting doubt on the many reliable observations of lava at very high temperatures, nor that he finds any difficulty in believing that lava may be brought to the surface at white heat. His contention is that such high temperatures are rare and, at Kilauea, would soon result in a return to the former condition of main-crater activity. At Vesuvius, in 1906, the lava

FIG. 3.



FIG. 3. Pot and chain, filled and covered with lava taken from "Old Faithful." (Photo by H. R. Schulz.)

flowed from a fissure on the southern flank at five meters per second while jets of liquid fragments shot directly from the central conduit a thousand meters into the air; at Etna, in 1910, the lava, at its source, had even greater velocity, with flames of burning gas ten meters in length; Stromboli, in 1907 and 1912, shot the liquid contents of its conduit into view in magnificent fiery spray, and the lava fountains of Kilauea, in 1911, were *tele*-photographed in $1/4$ second, at midnight, with a working aperture of F. 10,—none of these conditions involved a temperature approximating white heat.

The expedition not being provided with apparatus for the collection of gases, it was determined to, at least, attempt the taking of lava directly from a fountain by means of the cables.

A plumbers' solder pot, attached by a heavy iron chain to a steel lowering cable, formed the recipient and, by great good fortune, the experiment was immediately successful—"Old Faithful" engulfing the pot and chain—and, although the strain nearly wrecked the entire plant, the very spring of the main cable aided in the immediate withdrawal of the recipient which, brought to shore, presented the appearance shown in fig. 3. The pot and chain—just too hot to be touched—were hung from a beam in the station and, at the expiration of three

FIG. 4.



FIG. 4. Section of contents of pot showing three zones of consolidation.

hours, were still at *virtually the same temperature*, while, during the fourth hour, the entire mass turned cold. This result was unlooked for—and the taking of regular temperature readings neglected—because of the negative result of an experiment on the Etna lava of 1910, when pyrometer readings were taken at one minute intervals, by the writer, on a cooling mass of lava. In that case the temperature fell from 970° C. to 150° C. in an hour, but without any notable abnormality in the regularity of its descent. The probability would seem to be that, in the case of the Etna lava, the first phases of crystallization had already progressed to an extent incompatible with further development in this short time of cooling, while this Kilauean fountain lava is so pure a glass that the beginning

of crystallization may occur even in so small a mass of material, evolving, in the process, a large amount of heat.

On examining the material it was found, as expected, that all the lava upon the chain and that on the outside of the pot was in the condition of glass. That inside the pot showed, in section, three distinct zones (fig. 4), the outer, of the same glass; the next, a layer of gray, semi-crystalline rock, and, finally, a central mass of the same nature but even more vesicular and of a slightly pinkish color. The walls of the gas cavities are of a smoothness indicating a considerable gas tension. It is interesting to note that, in other instances of moderately rapid consolidation, the writer has found the same

FIG. 5.

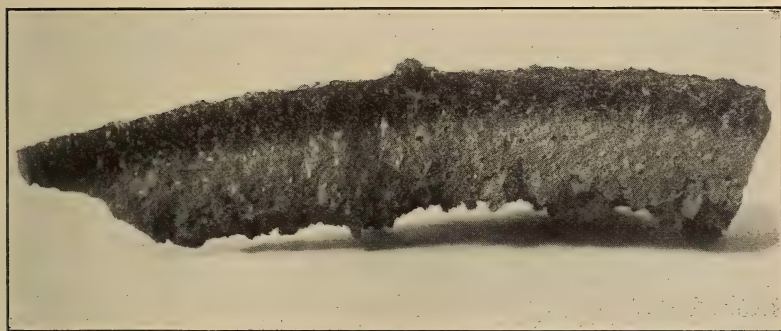


FIG. 5. Section of sheet pahoehoe showing three zones of consolidation.

division into three zones, as shown in fig. 5, representing a section of sheet pahoehoe, 3^{cm} in thickness, from a drained pool on the floor of the main crater.

As regards this lava from "Old Faithful," if we consider its source, the gaseous nature of fountain mechanism, and the almost instantaneous solidification of the outer layer of the collected mass, it will be difficult to conceive of a more fresh, more original and unaltered material, and its interesting and significant evolution of heat, upon consolidation, was not needed to demonstrate the value of this product for chemical and physical examination. A portion, in section, was sent by the writer to Dr. Albert Brun, whose methods of examining lavas are so well known, and he has most kindly responded with the very interesting note herewith appended and to which the reader's attention is now invited.

Note on the Lava taken from the Halemaumau Pit by Mr. Frank A. Perret in July, 1911, with gas analyses and remarks by ALBERT BRUN.

In the accompanying article, Mr. F. A. Perret shows that he has been able to get, out of "Old Faithful," lava still in a state of fusion. This interesting experiment, carried out with much skill, made it possible to study in the laboratory a lava which was taken when in the midst of the process of evolution. The points which I examine in this note only include a few facts relating to the gases, as well as those relating to the action of steam on the magma. In addition I also examine a special feature in the evolution of crystallization of the melted magma of Kilauea.

Gases.—It is well known that, during the last century, the French astronomer, Jansen, discovered with the spectroscope, that the flames which escaped from the lava lake of Kilauea gave the spectrum rays of sodium, C, and H_2 . The gas analyses published during recent years by myself in my book "*Recherches sur l'Exhalaison volcanique*" (1911, page 115) confirm this composition. The lava in fusion obtained by Mr. Perret in 1911 also gives out gases, the nature of which confirms the above mentioned analyses.

To extract the gases, I heated the glassy lava in a vacuum nearly to the melting point, or to complete fusion. This operation took place in an apparatus already described. It distills quite a quantity of hydrocarbides which are condensed in the form of black bituminous rings which colored P_2O_5 yellowish brown. It also deposited a white ring of $(Na,K)Cl$ and NH_4Cl which can be easily analysed. It is known that the composition of a complicated mixture of gases is influenced by the duration of the time of heating, the temperature, the pressure and the partial pressure of each individual gas, so that the final result is somewhat variable, even with the same materials. But the importance of this slight variation need not be exaggerated.

The lava collected by Mr. F. A. Perret gives off the following gases:

A—Lava heated to complete fusion for a long time; from 1 kilogram of lava.

Solid matters:

Chlorides $(Na,K)Cl$ volatilized, milligrams..... 75

Salmiac (NH_4Cl) id. id. 15

Bitumen very abundant

Gases: Quantity in cubic cent. 310^{cc}

Contained Cl_2 traces

HCl 4.6

SO_2 14.4

CO_2 67.0

CO 8.

H_2 5.

N_2 1.

100.0

I have explained elsewhere the presence of CO. The examination of the composition of these gases, as well as of the substances volatilized and easily condensed at the ordinary temperature, shows immediately that a great part is combustible. On coming into contact with the atmosphere these substances will burn, owing to the high temperature which they possess on leaving the magma in fusion. Therefore there will also be formed CO₂, and water of *extra magmatic origin*.

This, therefore, easily explains the flames, giving more or less light, which observers have seen rising from Lake Halemaumau. It is also advisable to note that these gases contain very little N₂. The percentage of N₂ will always be a criterium of great general importance, which will denote the purity of the gaseous products collected on the spot, either from a fumarole or from the liquid lava.

Oxidization of the Lava (by water).—The lava collected by Mr. F. A. Perret from "Old Faithful" is not completely oxidized. After having extracted all the gases from it, there remains a melted mass of black silicates, opaque even in thin splinters; this mass is rich in C. Therefore the silicate does not contain enough peroxides in order to oxidize all its C at the temperature of the lake. But if we supply the necessary O₂, either in the form of water or air, we shall be able, at the temperature of the lake, to oxidize all the C easily, and to obtain a great quantity of CO₂ and H₂; therefore this experiment proves that the magma did not contain enough water to oxidize all its C.

This demonstration may be made, in a very elegant way, as follows: Let us take the black silicate residue which during the first heating gives off all its gases, and its volatile substances, and which only contained a residue of carbon. This residuum must be heated in a closed apparatus in the presence of steam and nothing else, and without any traces of atmospheric air. A manometer shows the pressure, at every moment, of the gases formed at the given temperature. In the course of the heating a reaction is developed. The water attacks the lava and its carbon. The pressure in the apparatus which I used reached 500 millimeters of mercury at 1000°.

Under the same conditions the gases of lava *alone, without the action of the water*, only give a pressure of 8–10 millimeters of mercury. The gases collected during this intense reaction have the following composition; B, first exp't; C, second exp't:

Composition of the gases.		
	B	C
SO ₂ -----	} 26·2	0·25
CO ₂ -----		19·4
CO -----		6·4
H ₂ -----	5·0	74·0
N ₂ -----	68·0	traces
	0·4	
	99·6	100·05

The quantity given off from 1 kilogram of lava depends on the quantity of water. I obtained 4000 to 6000 cubic cent.

It is advisable to remark, that the quantity of gases collected is enormously greater than that obtained by the study of the apparent density of the natural vesiculated lava. In our experiment the water oxidizes the lava continually until the chemical equilibrium is reached. This reaction, which we accomplished in the laboratory, does not take place in the magma of the volcano, for the latter contains a residue of carbon. Therefore, if there was any steam, it was in too small a quantity to attack all the C. The proportion reached so low a limit that it is almost nothing.

This enables us to say: that the magma of Kilauea is anhydric, with the exception of the enclaves, and in special cases, (as explained in my *Recherches sur l'Exhalaison volcanique*, p. 264,) it even seems that this proposition may be extended to the ancient magmas, such as granites. For we know that white and black micas are not chemically hydrated minerals, as has hitherto been admitted. For the details concerning this proposition, which seem to be extraordinary, see *Bulletin de la Société minéralogique de France*, Feb., 1913, and *Archives des Sciences*, Genève, xxv, No. 5.

Crystallization.—We wish to draw attention to the interesting point brought to light by Mr. Perret's skilful experiment. The lava was indeed collected at the very time of its volcanic and crystalline evolution; as before explained, a fairly large mass of lava was extracted from the "Old Faithful." When he got the lava in fusion, from the pit, Mr. Perret brought up a glass in which some crystals were floating (labradorite, peridot, and more rarely augite of old formation). Several of these crystals are in the course of digestion. They are corroded and the edges rounded, which shows them to be debris of enclaves. Other crystals have clear cut and sharp angles: they probably are in the course of formation.

The external part of the block, cooled suddenly, was consolidated into a limpid yellowish-green glass. The internal part, cooling more slowly, crystallized. There were no real crystals, but trichitic-centroradiated spherulites. These trichites are generally developed around a preexisting crystal; they form around it a dark-colored hairy setting, opaque in the center and transparent at the edges. The refractive index is greater than that of glass. The fibers are extremely fine, delicate and indistinct in form. It is easy to recognise, with polarized light, the characters of a spherulite, the fibers of which are elongated optically + (positive).

It is impossible to say whether a pure mineral is present. We are in presence of an intermediate state of crystalline evolution. This phenomenon appears in a very short space of time—a few hours. We must be grateful to Mr. Perret for having demonstrated experimentally, *on the volcano itself*, this interesting epoch in the life of the lava.

The present writer had intended commenting at some length on this most interesting report, especially as regards the question of anhydricity, but lack of space absolutely necessitates deferment of the discussion, which, to have any value, would be long. The results obtained by the writer's successors at Kilauea should throw great light upon the exact nature and proportions of the emanations; the field is a fertile one for direct research, and there can be no doubt that the observatory, now established and in charge of Professor Jaggard, will prove itself an institution of the greatest value to the growing science of volcanology.

Some of the more salient points brought out in the present series of papers on Kilauea.

1. Gaseous cause of the mechanism of lava fountains.
2. Three phases of fountain action distinguished.
3. Air oxidation (burning) of gases emanating from the lava.
4. The burnt gases from visible cloud readily photographed.
5. Islands supported by chilling to them of artificial shore and by gas flotation.
6. Formation of gas ducts to top of floating islands.
7. Formation of sub-surface cavity with lava dis-levelling and production of free flowing cascade.
8. Sinking of islands effected by lava overflows due to rapid changes of level.
9. So called "new islands" often due to chilling of lake surface by re-flotation of sunken island.
10. Circulation of lake initiated by gas explosion, and continued by sinking of heavy surface material.
11. Elongated form of lake necessary consequence of this principle of circulation.
12. Variations in height of lava column slightly influenced by atmospheric pressure changes.
13. More strongly by luni-solar gravitational influence.
14. Pronounced sinking of lava after gaseous outburst.
15. Crater ledges may subside so gradually and by so minute a subdivision as to constitute a "slow flow."
16. Evidence of *many* explosive phases in the past of Kilauea.
17. Characteristically tail-less bombs.
18. "Péle's tears."
19. Strong evidence from native tradition as to antiquity, normal origin, explosive, activity, etc. of Kilauea.
20. Monolithic consolidation of stagnant lava.
21. Shell or tubular consolidation of flowing lava.

22. "Pressure casting" of trees.

23. Permanence of crater and conduit walls, floating islands, etc., due to slowly consolidated lava having higher fusing point by reason of crystallization.

24. Temperature of modern lake shown to be from 1050° to 1175° C—possibly from 1000° to 1200° .

25. Appearance of white heat often due to absorption of yellow rays by transparent burnt gases.

26. Thermo-electric element preferable to electric resistance thermometer for field work.

27. Chemical and physical characteristics of fountain lava collected directly.

Posillipo, Naples, August, 1913.

ART. XLIII.—*Observations on the Stem Structure of Psaronius Brasiliensis*; by ORVILLE A. DERBY.

[Preliminary note in advance of the Annaes do Serviço Geologico e Mineralogico do Brasil.]

It having been recently established by Count Solms-Laubach* that the slice of a *Psaronius* trunk preserved in the Paris museum, which has become so well known through the studies of Brongniart and Zeiller under the name of *Psaronius brasiliensis* (possibly not identical with the fossil so named by Unger), is a part of a specimen taken, in 1839, from the National Museum of Rio de Janeiro to Paris to be cut, and that other slices were preserved in the museums of Rio de Janeiro, London and Strasbourg, it occurred to me that, having the Rio slice at hand, there was a possibility of determining through the aid of photographs and dimensional notes on the other slices, the relative position and mutual relations of the different known parts of the original trunk. Through the extreme courtesy of Drs. J. B. Lacerda and A. Smith Woodward of the Rio de Janeiro and London museums, of Prof. R. Zeiller and Count Solms-Laubach of Paris and Strasbourg, the necessary material for the projected study was readily obtained.

The alignment of the various slices, represented individually in fig. 1,† was found to be an easy matter, since one face of each of the Paris and Strasbourg ones, having been only partially evened up by cutting, retains a part of the original fractured surface and thus shows that these are the stub ends of the original specimen. Between these end slices the Rio and London ones readily fall into place through the agreement of accidental and structural features on the opposing sides of the saw cuts by which they had been separated. The Rio slice, not having been evened up, shows that in the first cutting nearly 5^{mm} of material must have been lost and in the restorations in figs. 2 and 3 this width has been assigned to the various saw cuts, though it is probably too great for those subsequently made. According to information received from Prof. Zeiller a thin slice (5^{mm}±), now in the Paris museum, was cut from the lower end of the original Paris specimen to even it up, and apparently a similar operation had been performed on the upper end of the first London one, since its

* Über die Schicksale der als *Psaronius brasiliensis* beschriebenen Fossilreste unserer Museen, Festschrift zur Feier des 70. Geburtstages von P. Ascherson, 1904.

† These sections, as also those of figs. 2 and 3, are about two-fifths natural size.

FIG. 1.

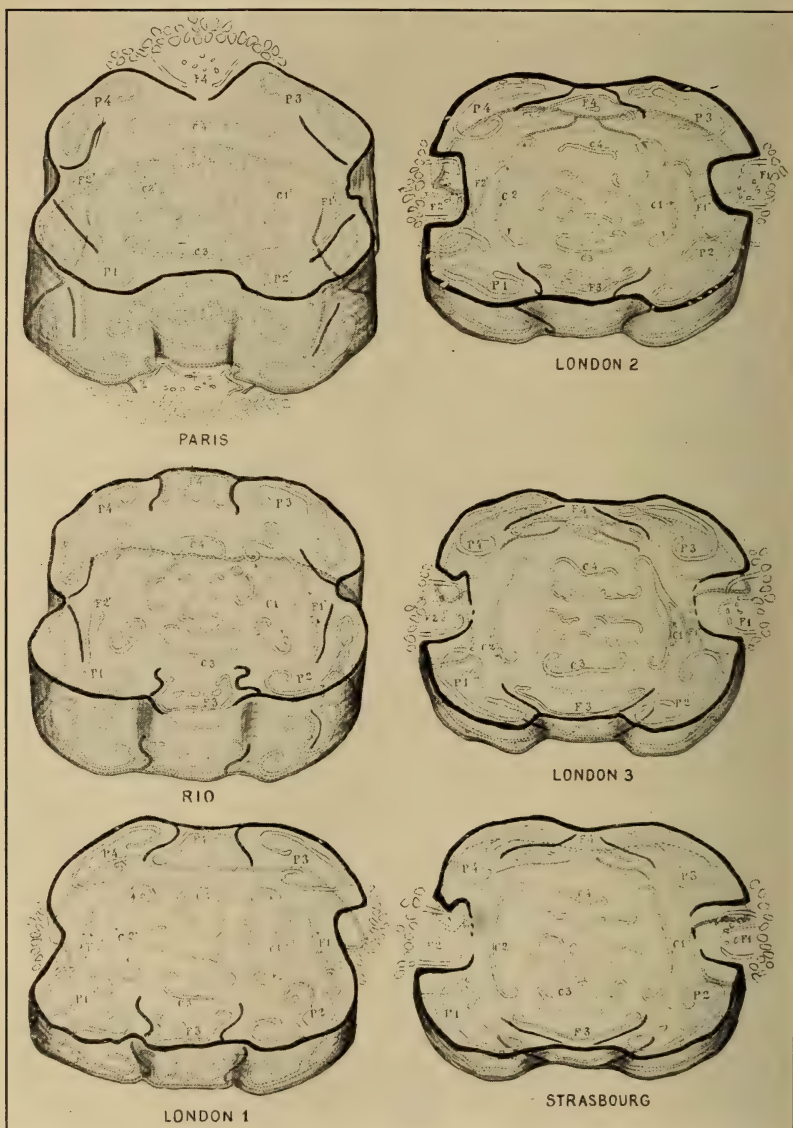
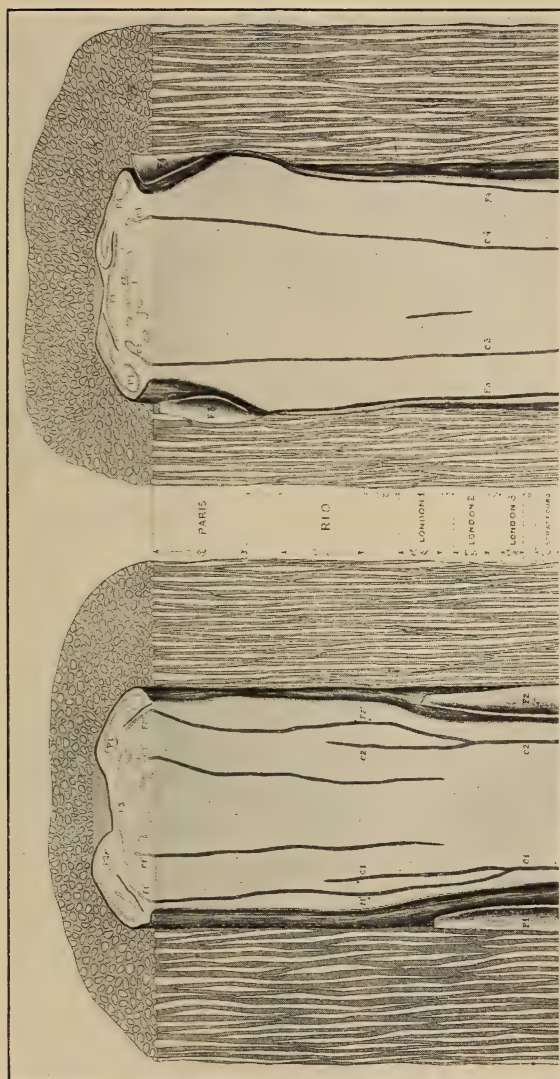


FIG. 2.



mechanical features do not agree with those of the corresponding face of the Rio slice. As will be readily seen in fig. 2, in which the thickness of the various slices and the width arbitrarily assigned to the intervals are represented, any inaccuracies that there may be in the latter do not materially affect the restoration of the original specimen.

Based on careful plotting from photographs of the twelve cross sections, Mr. Francisco Basto, draughtsman of the Brazilian Geological Service, has prepared the figures given on the accompanying plates ($\times \frac{2}{3}$). In those of fig. 1 the central stem of the various slices is drawn as if divested of its root sheath and inclined at an angle of 45 degrees, thus giving an apparent inequality to the two axes which in reality are substantially equal. The real inequality, due to the unequal development of the involving root sheath, of the two axes of the entire trunk is shown in the ideal longitudinal sections of fig. 2. In the restoration, fig. 3, of the preserved parts of one member of each of the three pairs of F strands the figures are so placed that if imagined dislocated laterally so as to fall into line an almost complete representation of the stem portion of a single strand of this group will be obtained. In order to permit a better representation of certain features, the interval between the Paris and Rio slices has been left open. In the designation of the strands Prof. Zeiller's nomenclature of P (eripheral) and F (oliar) has been preserved for the two outer groups with a modification in the numbering of the latter rendered necessary by the introduction of an additional pair not known to him, while the central group, of which only the outer members are marked, is designated by the letter C.

An inspection of these figures makes it evident that the original specimen represented a fragment of a trunk broken somewhat above the points of emergence of a pair of oppositely placed external organs carrying the vascular strands F1 and F2, and again somewhat above the emergence of a crosswise placed pair (F3, F4) of organs of the same kind. Of the last pair the strands of F3 are completely outside of the sclerenchymous sheath on the lower face of the Paris slice, while F4 is still enclosed within it, and correspondingly the former is seen to have disappeared before the level of the upper face of the slice was reached, while the latter still persisted at this level, showing that an interval of a few millimeters of growth intervened between the emergence of the two members of each pair. On the other hand, the interval between the successive pairs of this set was not far from two hundred millimeters.

The numerous strands of the C group are neatly arranged in the Strasbourg and London 3 slices in a loose rectangular bundle with a pair of long bounding strands (C1, C2) on the

longer sides and of short (C3, C4) strands on the shorter one. This symmetrical arrangement becomes disorganized higher up through the breaking up and subsequent disappearance of the longer pair, but is restored, in a reversed position, at the top of the Paris slice through the increased development of the C3, C4 pair and the appearance of a new (C1', C2') pair in substitution of the one that was lost. The central group of strands thus shows a periodicity at about the same levels as that above noted in the F group.

The cut between the Strasbourg and London 3 slices caught, on its upper side, the beginning of a branch of the C1 strand and for this reason this strand and its development have been selected for restoration. Before reaching the top of the Rio slice the parent C strand disappeared while the branch developed into a typical F (F1') strand and a pair of sclerenchymous bands developed outside of it. At the top of the Paris slice this strand and its accompanying sclerenchymous bands are so nearly in the same stage of development as the F3 strand in the Strasbourg slice that the latter may be taken as representing its missing portion. On tracing this strand and its bands upward their sides are seen to draw inwards until they assume the shape presented on the upper face of the Rio slice where the portion of the sclerenchymous sheath in front of the strand has ceased to form. In the interval between the Rio and the Paris slices the internal sclerenchymous bands evidently became completely soldered to the outer sheath and had their inner margins united so as to make the sheath again continuous, while the strand became external and divided into two parts through the loss of its central portion. Before reaching the top of the Paris slice this strand disappeared, but its companion shows one phase of its missing portion and is so like the F1 strand in the Strasbourg slice that this may be taken as representing the other phases susceptible of preservation in the silicified trunk of the plant.

In view of the history traced above, the F1, F2 pair of strands in the four lower slices must be regarded as the remnants of persistent stub ends of the stalks of a pair of external organs that emerged from the trunk somewhat lower down and developed parallel with it in deep grooves produced by the formation of sclerenchyma behind them, up to near the top of the London 1 slice where the organs spread out laterally to form a part of the crown of the plant. Eventually the crownpart of these organs fell away, leaving the basal portion adherent to the trunk, where they were subsequently covered by adventitious roots, descending from above, and thus protected from complete decay. Before the formation of the root covering these stubs would be exposed to the air and thus

subject to decay, which seems to have destroyed all their softer tissues, leaving only the lignified strands. This conclusion is based on the fact that the greater part of the space within the grooves is occupied by open cavities or by a filling of silica in which traces of organic structure are obscure or lacking. Aside from the F strands, which are tolerably distinct in these grooves, a number of rounded spots occur that look like cross sections of roots, but which may prove to be accidental. As the doubt regarding the true character of these markings can only be resolved by a microscopic examination, which there is no opportunity of making, they have been left out of account in the restoration.

The mode of formation of the sclerenchymous sheath behind the emergent organ is shown in the seven lower sections of the trunk. In the interval between the incurred sides of the internal sclerenchymous bands aligned shreds of sclerenchyma appear which continue detached until the fall of the organ, when they unite with each other and with the bands and thus become, with these, an integral part of the trunk sheath.

It is to be noted that the cross sections present no indications of a sclerenchymous covering of the stem of the organ itself, from which it may be concluded that this, aside from being ephemeral, could have had no great extension, giving it a considerable weight, in its missing outspreading portion, since its only mechanical support seems to have been that afforded by the vascular strands.

The four P strands are essentially alike in the uppermost cross section of the trunk,* where each presents the form of a broad ribbon slightly arched in its central portion and strongly inrolled at the margins, with a loose semicircular curve on one side and a more compressed semielliptical one on the other. With a reversal in the position of the two types of inrolling, this simple form of the ribbon recurs also in the lower cross sections, in which, however, there is a departure from symmetry through the division of P3 into two parts which become united in the interior of the London 2 slice, though the peculiar loop of the smaller division persists for some time and the strand only becomes normal at the top of London 1. It is to be noted that the compressed subelliptical inrolled margin of these strands lies between the trunk sheath and an internal sclerenchymous band where this stands subparallel to the sheath.

* As noted above this cross section has only been partially cut so that it presents, in part, an irregular fractured surface on which some of its structural features do not appear clearly in the photograph at hand. I owe to the extreme kindness of Prof. Zeiller an accurate sketch of the stem portion of this cross section.

The simple form presented by the P strands in the extreme cross sections is modified in some of the intermediate ones by branching and subdivision. An external branch appears on P1 at the base of London 1, and on P2 at the top of London 2, but in neither case does this persist to the succeeding cross section. An internal branch that becomes strongly developed and subdivided in the interior parenchyma seems to be a feature common to all of this set of strands. This is best seen on the P1 and P2 strands on the faces of the London 1 and Rio slices. In the case of the former the subdivided distal end of the branch seems to have soon ceased to grow, while the proximal end forms with the reunited shattered portions of the parent strand the peculiar open loop seen at the top of the Rio slice. In the next cross section above this loop is closed, but at the top of the Paris slice it is opened in such a way as to restore the simple form of the strand. As each of the other strands presents a similar loop in a more or less perfect stage of development, this seems to be a normal feature in the growth of this set of strands.

The detached subdivisions of the branches of the P strands assume the aspect of the smaller members of the central group, but as they lie outside of the magic square above noted and soon come to an end, a real connection between the P and C groups of strands seems improbable. A possible connection between the P and F groups is suggested by the relative position of P2 and F1' on the two faces of the Rio slice and of P3 and F1' on the lower face of the Paris one, but in neither case can an actual anastomosis be positively affirmed.

While it seems possible and even probable that anastomoses do occur between the P set of strands and one or the other, or both, of the two other sets, it is evident that the maintenance of such inter-relations cannot be the main function of the strongest and most persistent group of vascular strands that the plant possessed. Thus the conclusion seems forced upon us that the P strands must have supplied external organs that constituted a part, and presumably the main part, of the crown of the plant. In this case, however, these organs must have been persistent during a period of growth longer than that represented by the length of the entire fraction of the original trunk here considered; or a substitution of an old set of four organs by a new one must have taken place in the zone in which the strands are branched and shattered. This last hypothesis involves that of a continued upward growth of the sclerenchymous sheath on the outside of the P strands, whereas in the case of the F strands this growth, as shown above, was alternately on the outer and on the inner side of the strand.

The cross sections of the stem show a few root sections traversing the sclerenchymous sheath or situated between it and the adjoining P strand, but these are so limited in number as compared with the thousands that make up the great root sheath encircling the stem, that they must apparently be considered as sporadic. This consideration and the fact that the roots descend vertically in a space several centimeters wide wholly outside of the stem sheath, suggests the hypothesis that they arise, for the most part, from the proximal free portion of outspreading external organs that formed the crown of the plant, and that furthermore these organs must have been supplied by both the P and the F set of strands. A confirmation of this hypothesis appears to be given by the fact that in the grooves of the Rio slice the root covering is so loosely adjusted to the sclerenchymous sheath that open canals traversing the entire slice exist at the bottom of the grooves. The canal on the left side is so straight that a large-sized rigid needle can be freely passed through it. The other one, though larger, is not so freely open, but apparently through a deposit of silica in its central portion rather than from root growth within the groove.

Fully cognisant of the deficiencies of my knowledge of botany, it is only with the greatest reluctance and in view of circumstances that made it almost impossible to confide the study of this subject to more competent hands, that I have ventured to occupy myself with the present study, in which, except in one or two instances, I have refrained from attempts at interpretation of the facts observed, as well as from the use of a nomenclature that involved such interpretation. In submitting the case to the judgment of those competent to judge it, I limit myself to recording the fact that in the course of this work the apparent analogy of the plant here considered with the female representatives of the genus *Cycas* growing about me has been constantly present to my mind.

Rio de Janeiro, July 12, 1913.

ART. XLIV.—*The Fauna of the Florissant (Colorado) Shales;*
by T. D. A. COCKERELL.

ALTHOUGH the fauna of the Miocene shales at Florissant has been much studied in recent years, no summary has been published since 1906 (University of Colorado Studies, III, pp. 163-168). It is not possible for a student of general geology or palæontology to ascertain precisely what is known from Florissant to-day without a good deal of bibliographical research, and the data compiled in 1906 are no longer in any sense adequate. I therefore present a concise summary, complete to the present date (July 11), but including only described and published species. Families or groups marked with an asterisk are no longer found in North America, while those marked with a dagger are wholly extinct. Genera are only cited when they are extinct and do not fit comfortably into the recognized modern families.

AVES.	
Charadriidæ.	1.
Passeres.	1.
PISCES.	
Amiidæ.	2.
Catostomidæ.	3.
Siluridæ.	1.
† Trichophanes.	2.
Total Vertebrata.	10.
MOLLUSCA.	
Zonitidæ.	2.
Limnæidæ.	4.
Sphæriidæ.	1.
Total Mollusca.	7.
COLEOPTERA.	
Anthicidæ.	1.
Anthribidæ.	7.
Bostrychidæ.	3.
Bruchidæ.	11.
Buprestidæ.	7.
Byrrhidæ.	7.
Calandridæ.	7.
Carabidæ.	33.
Cerambycidæ.	10.
Chrysomelidæ.	11.
Cleridæ.	1.
Coccinellidæ.	2.
Colydiidæ.	2.
Cryptophagidæ.	1.
Cucujidæ.	3.
Curculionidæ.	95.
Dasyllidæ.	2.
Dermestidæ.	3.
Dytiscidæ.	6.
Elateridæ.	3.
Erotylidæ.	2.
Hydrophilidæ.	8.
Lampyridæ.	3.
Lathridiidæ.	1.
Lucanidæ.	2.
Lymexylidæ.	1.
Malachidæ.	2.
Melandryidæ.	1.
Meloidæ.	2.
Mordellidæ.	3.
Mycetophagidæ.	2.
Nitidulidæ.	6.
Otiorhynchidæ.	18.
Parnidæ.	4.
*Paussidæ.	2.
Ptinidæ.	2.
Pythidæ.	1.
Rhipiphoridæ.	1.
Rhynchitidæ.	23.
Scarabæidæ.	16.
Scolytidæ.	4.
Silphidæ.	6.
Staphylinidæ.	45.
Temnochilidæ.	1.

Tenebrionidæ. 7.
 Trogositidæ. 1.
Total Coleoptera. 379.

HYMENOPTERA APOIDEA.

Megachilidæ. 9.
 Ceratinidæ. 1.
 Anthophoridæ. 1.
 Bombidæ. 1.
 Panurgidæ. 2.
 Andrenidæ. 10.
 † Protomelecta. 1.
 † Cyrtapis. 1.

HYMENOPTERA SPHECOIDEA.

Crabronidæ. 2.
 Pemphredonidæ. 2.
 Philanthidæ. 2.
 Nyssonidæ. 2.
 Sphecidæ. 2.
 Larridæ. 1.
 Mellinidæ. 1.

HYMENOPTERA VESPOIDEA.

Anthoboscidæ. 4.
 (Cosilidæ of Ashmead.)
 Pompilidæ. 7.
 Scoliidæ. 1.
 Vespidae. 3.
 Eumenidæ. 3.

HYMENOPTERA FORMICOIDEA.

Poneridæ. 1.
 (Many ants have been collected, but not yet described.)

HYMENOPTERA PARASITICA.

Agaonidæ. 1.
 Alysiidæ. 3.
 Belytidæ. 2.
 Bethylidæ. 1.
 Braconidæ. 19.
 Chalcididæ. 4.
 Chrysididæ. 2.
 Cleonymidæ. 1.
 Cynipidæ. 1§
 Diapriidæ. 2.
 Eurytomidæ. 2.

Evaniidæ. 2.
 Figitidæ. 1.
 Ichneumonidæ. 76.
 Proctotrypidæ. 1.
 Pteromalidæ. 1.
 Stephanidæ. 1.
 Torymidæ. 6.

HYMENOPTERA PHYTOPHAGA.

Cephidæ. 1.
 Xyelidæ. 1.
 Lydidæ. 2.
 Oryssidæ. 1.
 Tenthredinidæ (s. lat.) 29.
Total Hymenoptera. 217.

LEPIDOPTERA.

Nymphalidæ. 9.
 Pieridæ. 1.
 Tortricidæ. 1.
 Cœcophoridæ. 1.
 † Phylledestes. 1.
Total Lepidoptera. 13.

DIPTERA.

Asilidæ. 8.
 Anthomyiidæ. 1.
 Bibionidæ. 2.
 Bombyliidæ. 8.
 Cecidomyiidæ. (gall). 1.
 * Glossinidæ. 2.
 Leptidæ. 3.
 Mycetophilidæ. 4.
 Nemestrinidæ. 5.
 Phoridæ. 2.
 Platypezidæ. 1.
 Ptychopteridæ. 1.
 Sciomyzidæ. 1.
 Stratiomyidæ. 1.
 Syrphidæ. 3.
 Tabanidæ. 2.
 Therevidæ. 2.
 Tipulidæ. 53.
Total Diptera. 100.

HETEROPTERA.

Belostomatidæ. 1.
 Capsidæ. 13.
 Coreidæ. 33.

§ The gall *Andricus myricæ* Brues, 1910, is the same as *Cecidomyia* (?) *pontaniformis* Kkll., 1908.

Corixidæ. 4.
 Hydrobatidæ. 1.
 Lygæidæ. 47.
 Notonectidæ. 1.
 Pentatomidæ. 33.
 Pyrrhocoridæ. 2.
 Reduviidæ. 3.
 Tingitidæ. 3.
 Veliidæ. 2.
Total Heteroptera. 143.

HOMOPTERA.

Achilidæ. 1.
 Aphididæ. 32.
 Cercopidæ. 21.
 Cicadidæ. 3.
 Cixiidæ. 8.
 Coccidæ. 1.
 Dictyopharidæ. 1.
 Fulgoridæ. 3.
 Jassidæ. 11.
 Psyllidæ. 3.
Total Homoptera. 84.

NEUROPTEROID SERIES.

Ephemerida. 7.
 Embiidæ. 1.
 Termitidæ. 7.
 Meropidæ. 1.
 †Eobanksiidæ. 1.
 Panorpidæ. 3.
 Raphidiidæ. 8.
 Chrysopidæ. 6.
 Hemerobiidæ (s. lat.) 3.

*Nemopteridæ. 1.
 Æshnidæ. 5.
 Agrionidæ. 11.
 Trichoptera. 28.
Total Neuropteroid Series. 82.

ORTHOPTERA.

Acridiidæ. 7.
 Blattidæ. 3.
 Forficulidæ. 10.
 Gryllidæ. 1.
 Locustidæ. 8.
 Mantidæ. 2.
 Phasmidæ. 1.
Total Orthoptera. 32.

APTERA.

†Ballostoma. 1.
 (? an insect larva.)
 Lepismatidæ. 1.
Total Aptera. 2.
Total Insecta. 1052.

ARACHNIDA.

Acarina. 1.
 Araneida. 31.
 Phalangida. 1.
Total Arachnida. 33.

DIPLOPODA.

Julidæ. 1.

CRUSTACEA.

Ostracoda. 1.

TOTAL ANIMALIA. 1104.

A species of the Dipterous genus *Mydas*, representing an additional family (Mydaidæ), has been described and sent for publication.

The plants from the same beds cannot at present be listed so accurately as might be wished, owing to some outstanding questions of generic position, synonymy and locality. Using my best judgment, however, I find that the apparently valid described species include two fungi, two mosses, two Characeæ, one Isoetaceæ, five Polypodiaceæ, one Schizaceæ, seven gymnosperms, eleven monocotyledonous and 181 dicotyledonous plants. The so-called *Tmesipteris alleni* (Lx.) Hollick, although common, cannot be referred to any genus known to those who have examined it. It has nothing whatever to do with *Tmesipteris*, nor does it belong to *Salvinia* or *Ophio-glossum*, as placed by Lesquereux. It may be known for the present as *Carpolithes alleni* (Lx.).

ART. XLV.—*The Photoelectric Effect*; by LEIGH PAGE.

COMPTON* has shown that in measuring photoelectric currents corresponding to different accelerating potentials the contact difference of potential between the metal exposed to the ultra-violet light and the receiving electrode must be taken into account. As this contact potential difference may amount to one volt or more, and as the potentials used to retard or accelerate the emission of the electrons are generally not more than two volts, it is obvious that serious misapprehensions may result from the failure to make correction for it. Richardson and Compton† have shown that when this contact potential difference is taken account of, the saturation point is independent of the wave length of the ultra-violet light and of the nature of the metal, and always falls on the corrected axis of ordinates-zero volts. This leads to the conclusion that no helping field is necessary to cause the maximum emission of electrons under the influence of ultra-violet light, but that any hindering field, however small, will diminish the photoelectric current.

The following investigation was undertaken to verify the results obtained by Richardson and Compton when a photoelectric chamber of somewhat different design was used, to investigate the effect of scraping in vacuum the metals which were to be exposed to the light, and to obtain, if possible, experimental evidence as to the nature of the contact difference of potential between metals.

APPARATUS.

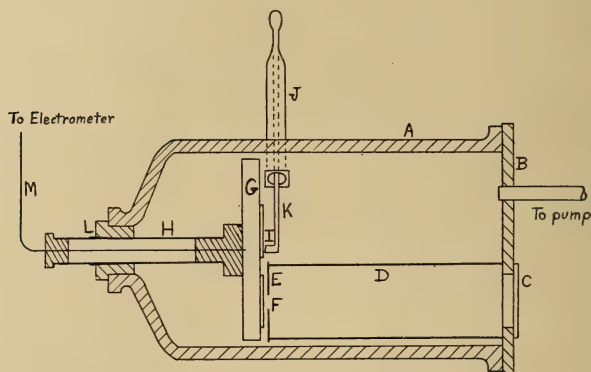
The photoelectric chamber consisted of the glass jar, A (fig. 1), the end of which was closed by the brass plate B. The light, after passing through the quartz window, C, traversed the tube, D, 12.8^{cm} in length and 3.5^{cm} in diameter. The end of this tube was covered by the plate, E, of the same metal, in the center of which was the circular aperture, F, 8^{mm} in diameter. The beam of light used was at this point not more than 4^{mm} in diameter, and passed as nearly as possible through the center of this opening. To the circular plate, G, were soldered disks of the metals on which the light was allowed to fall. By means of the tube, H, which could turn in the conical bearing L, G could be rotated so as to bring the various metals in front of the aperture, F. A steel scraper, I, was used to scrape the surfaces of the metallic disks before exposing them to the light. The scraper was similar to that

* K. T. Compton, *Phil. Mag.*, xxiii, p. 579, 1912.

† O. W. Richardson and K. T. Compton, *ibid.*, xxiv, p. 575, 1912.

used by Herrmann,* and consisted of a flexible lead tube, J, one end of which was soldered to the brass rod, K, bearing the tool, I, while the other end was fastened to the glass jar, A. In operating the scraper, the metal to be scraped was brought under the scraper by rotating the plate, G, and then the scraper was pressed down on the metal while the plate, G, was

FIG. 1.



rotated back and forth through a small angle. In all cases the area scraped was considerably larger than that exposed by the aperture, F. In this way the field near to the region exposed to the light was not complicated by the presence of unscraped surfaces. It was found to be not at all difficult to scrape appreciable shavings from the metallic surfaces, thus securing surfaces that were fresh and uncontaminated. Even after a few hours' fatigue in low vacuum the appearance of the surface would change quite noticeably from that of the freshly scraped metal.

The distance of the surfaces of the metal disks on G from the nearer surface of E was 2^{mm} . The interior of the glass vessel was lined with brass gauze (not shown in the figure) and this lining, together with the plate B, the tube D, and the scraper I (which, when not in use, was fastened at a distance of about 4^{mm} from the nearest point of G) could be raised to any desired potential. The tube H was kept earthed throughout the experiment. The wire M, insulated from H by an ebonite and an amber bushing, connected G with one pair of quadrants of a Dolezalek electrometer. The other pair of quadrants was earthed, and the needle charged to a potential

*Karl Herrmann, Verh. d. Deutsch. Phys. Gesellsch., xiv, p. 557, 1912.

of 80 volts. The volt sensitiveness of the electrometer was about 135 centimeter scale divisions.

A glass tube sealed into a hole in the plate B led to charcoal tube, drying tube, and pump. Throughout the experiment the charcoal tube was kept immersed in liquid air, and the vacuum was tested before each set of readings.

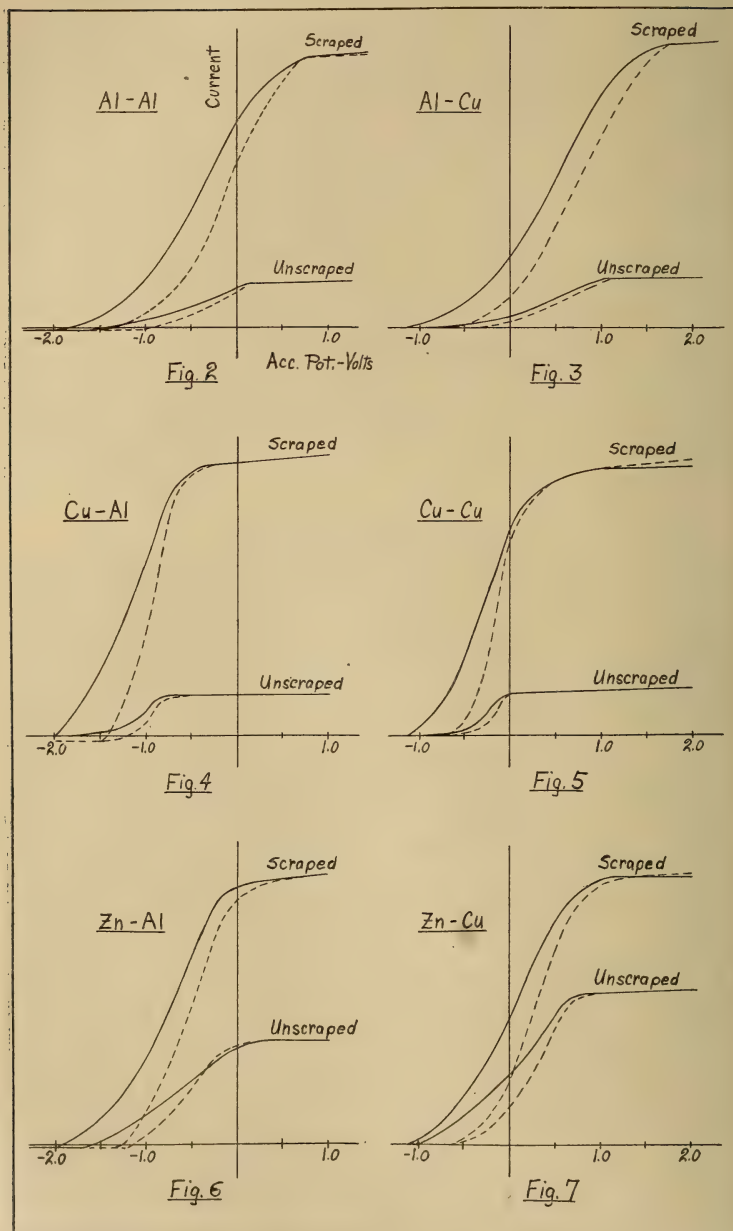
The source of light was a Cooper Hewitt Mercury Vapor lamp. The light passed through a Hilger spectrometer with quartz train, the slit of which was focused on the metal at G. Wave lengths used were 2460 and 2190 Ångström units. The lamp was found to burn very steadily, giving the best results with a current of 2.4 amperes, the maximum fluctuation in the current being not more than .03 amperes. A glass shutter operated by a heavy pendulum was found to be a very satisfactory instrument for regulating the length of exposures. When this method gave too small a deflection, a watch was used. In all cases the current was measured by noting the deflection of the electrometer corresponding to a given exposure.

EXPERIMENTAL PROCEDURE.

During the first part of the experiment the tube H was of copper. Later this was replaced by an exactly similar tube of aluminium. Each tube was thoroughly scraped before being inserted. The metal disks on which the light was allowed to fall were of copper, zinc, and aluminium. The design of the apparatus was such that very little trouble was experienced from reflected light. In fact the effect due to reflected light was inappreciable when the copper receiving electrode was in use. Even with the aluminium electrode this effect was so small that it was the cause of no trouble.

Immediately after scraping, the metals used showed a very large photoelectric fatigue. It was found impossible to take readings until this fatigue had very greatly diminished—a matter of some ten or fifteen minutes' delay. The readings were taken in the following order: First, the point of saturation, which had been previously roughly located, was determined by taking readings as rapidly as possible in the order of increasing accelerating potentials. As exposures of four or five seconds would usually suffice, these readings could be taken very quickly. The reason for taking the readings in the order of increasing accelerating potentials was so as to take them in the most unfavorable way, as regards fatigue, for producing the shift of the saturation point, which was noted in all cases of scraping. Second, the maximum velocity was determined by exposures of ten to twenty seconds. Occasionally the metal was rescraped and the maximum velocity determined at

FIGS. 2-7.



once. In no case was any difference found in the maximum velocity as thus determined and the maximum velocity as found by the method described above.

In figures 2-7 are plotted the photoelectric currents against the accelerating (positive) potentials in volts applied to the case and receiving electrode. The scale of ordinates is arbitrary, though the ordinates of the "scraped" and "unscraped" curves for $\lambda = 2190$ are in the proper ratio. Figures 2, 4, and 6 refer to the aluminium receiving electrode, and figures 3, 5, and 7 to the copper receiving electrode. The full line refers to wave length 2190, and the broken line to wave length 2460.

Readings were taken for each metal with each receiving electrode, both after scraping the metal, and after having exposed the metal to the air for fifteen hours or more. In the figures the latter are marked "unscraped."

DISCUSSION OF CURVES.

Comparison of figures 2 and 3, 4 and 5, 6 and 7 shows that the only effect of replacing the aluminium receiving electrode by the copper one is to shift the curves to the right relative to the current axis by 0.9 volt. This is quite exactly the case for the unscraped metals, and also for the Aluminium-Aluminium and Aluminium-Copper curves of the scraped metals. In the other cases of scraped metals the point of saturation is not so well defined, though the point where the curve meets the voltage axis shows a shift of very closely 0.9 volt. On account of the impossibility of always scraping to the same degree, and on account of the rapid fatigue immediately after scraping, which was particularly pronounced in the case of zinc, it was difficult to locate very precisely the saturation points in the case of the scraped metals. Moreover the method of taking readings, previously described, made the point of saturation, when there was much fatigue, less marked. Although the vacuum was good whenever readings were taken, saturation, in the case of the scraped metals, was not always complete until an accelerating potential of 4 to 6 volts was applied. This lack of complete saturation may have been due to reflected electrons.

All the curves show that the point of saturation is independent of the wave length used. This is a confirmation of the results of Richardson and Compton, and is seen to be true of the scraped as well as of the unscraped metals. In the Copper-Copper curve the saturation for the unscraped metal is seen to occur very exactly at zero volts. In the Aluminium-Aluminium curve this point comes a little to the right of the current axis, probably due to the fact that the treatment

accorded to the aluminium disk was slightly different from that accorded to the receiving electrode.

For any given wave length the uncorrected maximum velocity is seen to be independent of the nature of the metal which has been exposed to the light. This is quite closely the case for all curves. In the case of the scraped metals this point appears to be about 0.1 volt further to the left than in the case of the unscraped metals.

When the metal has been scraped not only is the maximum velocity point shifted about 0.1 volt to the left, but the saturation point is shifted about 0.5 volt to the right. This shift is quite clearly shown in all the curves except those in which zinc was the metal exposed to the light. In the case of scraped zinc the saturation points are much less distinct, due, no doubt, to the very rapid fatigue noticed in the case of zinc.

DISCUSSION OF RESULTS.

The shift of the curves to the left by 0.9 volt when the aluminium electrode was replaced by the copper one, in the case of both scraped and unscraped metals, is a conclusive confirmation of Richardson and Compton's contention that the contact difference of potential must be taken into account in plotting the curves. The fact that in the unscraped Copper-Copper and the unscraped Aluminium-Aluminium curves the saturation point comes practically on the current axis shows that this point corresponds to no field or true zero potential.

If the contact-difference of potential is allowed for, the maximum energies in volts are as follows:

		$\lambda = 2190$	$\lambda = 2460$
Scraped Al	} Al electrode	2.8	2.2
" Zn		2.3	1.7
" Cu		1.5	1.0
Scraped Al	} Cu electrode	2.8	2.3
" Zn		2.3	1.8
" Cu		1.6	1.1
Unscraped Al	} Al electrode	2.1	1.6
" Zn		1.9	1.4
" Cu		1.1	0.6
Unscraped Al	} Cu electrode	2.2	1.7
" Zn		1.8	1.3
" Cu		1.0	0.5

Einstein* has shown that the maximum energy L of the electrons emitted under the influence of light should satisfy the equation

$$L = h\nu - P$$

* A. Einstein, *Ann. d. Phys.*, xvii, p. 146, 1905.

where h is Planck's radiation constant, ν is the frequency of the light used, and P is the work done by the electron in escaping from the metal. Using $6.55(10)^{-27}$ erg sec. as the value of h ,

$$\begin{aligned} L &= 8.97(10)^{-12} \text{ ergs} - P & \text{for } \lambda = 2190 \\ L &= 7.88(10)^{-12} \text{ ergs} - P & \text{for } \lambda = 2460 \end{aligned}$$

From this result values of P as follows:

		$\lambda = 2190$	$\lambda = 2460$
Scraped	Al	$4.5(10)^{-12}$	$4.3(10)^{-12}$
"	Zn	$5.3(10)^{-12}$	$5.1(10)^{-12}$
"	Cu	$6.5(10)^{-12}$	$6.2(10)^{-12}$
Unscraped	Al	$5.6(10)^{-12}$	$5.3(10)^{-12}$
"	Zn	$6.0(10)^{-12}$	$5.7(10)^{-12}$
"	Cu	$7.4(10)^{-12}$	$7.0(10)^{-12}$

indicating a value of h somewhat less than $6.55(10)^{-27}$. That the values of P among the different metals differ very exactly by the contact difference of potential between these metals is made evident by the fact that the curves for different metals but for the same wave length meet the voltage axis at the same point.

The shift of the point of saturation to the right after scraping seems to throw some light on the nature of the contact-difference of potential. Since the point of saturation marks the true zero potential, the effect of scraping must have been to make the metal more electropositive. A similar effect when the scraping has been done in air at atmospheric pressure has been noted by other observers, and is commented on by Lord Kelvin in his paper on "Contact Electricity of Metals."* Now, on the surface layer theory of the contact potential difference, the degree to which a metal is electropositive depends on the degree to which it is covered by the surface layer. Hence any removal of the surface layer would make the metal less electropositive or more electronegative. Consequently it would seem that the contact potential difference cannot be due essentially to a double layer on the surface of the metal, though no doubt modified by the presence of such a layer.

Conclusions.

(1) By replacing the copper receiving electrode by one of aluminium it is shown that the contact potential difference should be corrected for as well when the metals which are exposed to the light have been scraped in vacuum as when they have been scraped in air.

* Lord Kelvin, *Phil. Mag.*, xli, p. 95 et seq., 1898.

(2) The maximum energies satisfy Einstein's equation, $L = h\nu - P$ provided a somewhat smaller value of h is used than that usually attributed to the radiation constant. This is equally true of scraped and unscraped metals.

(3) The shift of the saturation point (the true zero potential) in the direction of increasing electropositiveness after scraping in vacuum indicates that the contact difference of potential cannot be due essentially to a double layer on the surface of the metal.

The author wishes to acknowledge his indebtedness to Professor Bumstead for suggesting the subject of this investigation, and to Professors Bumstead and Boltwood for the suggestions they have offered and help they have given.

Sloane Physical Laboratory,
Yale University.

ART. XLVI.—*Graphical Methods in Microscopical Petrography*; by FRED. EUGENE WRIGHT. With Plates II to IX.

PROBLEMS can be solved, and relations between data of observation can be represented either by analytical methods or by graphical plots. Analytical processes, involving extended computations, are often cumbersome, but they must be used wherever exact results are required. Graphical methods of solution and representation, on the other hand, are usually easy to apply and frequently aid the observer in obtaining a clear picture of the relations which underlie some problem, particularly if geometrical conceptions of space be involved. They are, therefore, preferable to analytical methods in all problems in which a high degree of accuracy is not required or possible. They may also serve to verify the results of computation.

In geology and microscopical petrography the data obtained by measurement are not usually of such a high degree of precision that analytical methods of exact computation are necessary; experience has shown that the results furnished by graphical means are, as a rule, sufficiently accurate and in accord with the quality of the observational data. Graphical methods have, therefore, been generally adopted by petrologists and geologists in recent years in place of analytical methods. Geologists and petrologists have, moreover, daily to do with maps and are trained to picture and to interpret spacial relations from flat surface representations.

In microscopical petrography graphical methods serve three purposes: (1) to solve certain equations, (2) to represent data of observation and (3) to picture certain important crystallographic and optical relations.

In all these cases it is essential: (a) that the graphical means employed represent the relations adequately and as free from distortion as possible, and (b) that they are easy of application.

The first principle requires that, in any graphical representation, the relative accuracy over the entire field be uniform and comparable to that which obtains in nature. Great distortion is only to be tolerated when certain advantages are gained which more than counterbalance the effects of distortion. Thus the *gnomonic* projection is exceedingly useful in crystallographic work, notwithstanding its excessive distortion away from the pole, because in it all crystallographic faces are plotted as points and all zones as straight lines which, moreover, are so spaced in the projection that the crystallographic indices and elements of all faces can be read off directly. The *stereographic* projection, on the other hand, shows less distortion.

tion, but it lacks the straight equidistant zone lines and is inferior in this and other respects to the gnomonic projection for actual crystallographic work. For other purposes, however, it is superior to the gnomonic projection chiefly because it represents a less distorted image of the hemisphere. Other projections, notably the *equidistant* and the *angle*, distort still less and are, therefore, superior to the stereographic projection for certain purposes. No single projection, however, is superior to all others in every detail, and for this reason a number of different projections are in common use and will continue to be used, notwithstanding their defects, because for each given type of problem there is a projection which best meets the situation, and which, therefore, should be adopted, even though it may be unsuited for other kinds of problems involving projection.

In graphical plots for the solution of equations the principle of uniformity in relative accuracy over the entire plot is equally important and often leads the observer to modify an equation, which he wishes to solve, in such a way that the amount of distortion or lack of uniformity in plotting scale is decreased. This can be done either by taking some function of the values in question, as the logarithmic function, or by raising the values to some power. Experience is required to enable the observer to select such functions skilfully. This principle is well illustrated in Plate III (based on the equation $\sin^2 i = n^2 \sin^2 r$) which shows considerably less distortion than Plate II, although both plates furnish solutions of the ordinary refractive index equation $\sin i = n \sin r$.

The second principle, that of ease of application, concerns itself with the efficiency of the method, both in the solution of problems and in the preparation of the diagrams for such solutions. It is, however, obvious and requires no further comment.

In the following pages illustrations of these and other principles will be given and several new graphical plots will be described briefly.

Graphical solution of the equations used in microscopical petrography.—The most important equations which the petrographer has to solve in his work with thin sections and crystal plates are the following:

1. Refractive index formula

$$\sin i = n \sin r \quad (1)$$

wherein i is the angle of incidence, r , the angle of refraction, and n , the refractive index (Plates II, III, and IV).

2. Minimum deviation prism formula

$$n = \frac{\sin \frac{A+B}{2}}{\sin \frac{B}{2}} \quad (2)$$

where A is the minimum deviation angle, B , the prism angle, and n , the refractive index (Plates II and III).

3. Birefringence formula

$$\frac{1}{a'^2} - \frac{1}{\gamma'^2} = \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right) \sin \vartheta \cdot \sin \vartheta' \quad (3)$$

wherein ϑ and ϑ' are the angles included between the normal to a given birefracting plate and its two optic axes, a and γ the highest and lowest principal refractive indices of the mineral, a' and γ' the two refractive indices of the given crystal section (Plate V).

4. Approximate birefringence formula (Plate V).

$$\frac{\gamma' - a'}{\gamma - a} = \sin \vartheta \cdot \sin \vartheta'. \quad (4)$$

5. Optic axial angle formula

$$\tan^2 V_a = \frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{a^2} - \frac{1}{\beta^2}} \quad (5)$$

wherein $2V$ is the optic axial angle and a, β, γ , the three principal refractive indices of the mineral (Plates VI and VII).

6. Approximate optic axial angle formula (Plates VI and VII)

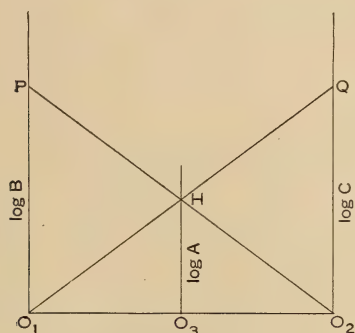
$$\tan^2 V_a = \frac{\gamma - \beta}{\beta - a}. \quad (6)$$

7. The transformation equations between the angles ϕ (azimuth) and ρ (polar distance), and the latitude and longitude angles, λ_1 and μ_1 , and λ_2 and μ_2 , as indicated in figure 1, in which ϕ is the angular azimuth of point P, ρ , its polar distance, λ_1 , its longitude, and μ_1 , its latitude when OE is the pole, and λ_2 , its longitude, and μ_2 , its latitude when ON is the pole. The transformation equations which connect these three sets of angles are:

quently than has heretofore been the case. It is a well-known principle in physics, but even there is not commonly employed. Logarithmic paper is the result of this principle and is of value wherever logarithmic functions are to be plotted.

Recently Dr. A. Hutchinson* has described a graphical plot—for use in connection with his total refractometer—in which this principle of plotting the functions directly has been employed. Such instances, however, are rare in petro-

FIG. 3.



graphic literature and this is the more surprising when we consider the importance and wide range of application of the principle.

Still another form of graphical plot might be used which is simpler to construct than Plates II to IX. It was not adopted, however, because of the pronounced distortion of the values represented. The construction follows from the fact that the relation

$$A = BC$$

can be written

$$\log A = \log B + \log C \quad (20)$$

If in this equation $\log B$ be considered constant, the general equation represents a set of straight lines passing through the point, $\log B$; similarly if $\log C$ be a constant we have a second set of straight lines passing through the point, $\log C$. If now we draw two straight parallel lines and plot $\log B$ to scale on the one line and $\log C$ to scale on the second, then, because $\log A$ is equal to the sum, $\log B + \log C$, we can determine the value of $\log A$ by means of a third straight line parallel to the first two (fig. 3).

* Mineralogical Magazine, xvi, 236-238, 1912.

The position of this line can be readily ascertained by assuming first that

$$\begin{array}{ll} \log B = 0 & \text{then} \\ \log A = \log C. & \end{array}$$

These two equations represent the line O_1Q . If now we assume that

$$\begin{array}{ll} \log C = 0 & \text{then} \\ \log A = \log B. & \end{array}$$

The last two equations represent the straight line O_3P .

Since the value $\log A$ is common to both lines it is at their intersection and the vertical line O_3 passes through the point thus found. This construction holds good for any two values of $\log B$ and $\log C$, whose sum is equal to $\log A$. In case the scales of $\log B$ and $\log C$ are of the same unit, then the line O_3K is located midway between O_1M and O_2N and the scale of $\log A$ is half that of $\log B$, and of $\log C$.*

On applying this method of plotting to some of the equations above, notably the refractive index equation 1 and the transformation equation, $\sin A = \sin B \sin C$, I have found that the distortion in the logarithmic trigonometric functions is so great that it renders this general method of little value in the graphical solution of trigonometric formulas. The first methods outlined above are, therefore, better adapted for the purpose. The logarithmic principle is, however, invaluable in certain problems; on it the slide rule is based.

Refractive index formula.—Plates II, III, and IV are given to illustrate how the same equation can be treated so that the relative accuracy of different parts of the plot is greatly changed. Plate II is based on the formula $\frac{\sin i}{n} = \frac{\sin r}{1}$

(fig. 4a), Plate III, on the equation $\frac{\sin^2 i}{n^2} = \frac{\sin^2 r}{1}$ (fig. 4b) and

Plate IV, on the equation $\frac{\sin^2 i}{\sin^2 r} = \frac{1}{\frac{1}{n^2}}$ (fig. 4c).

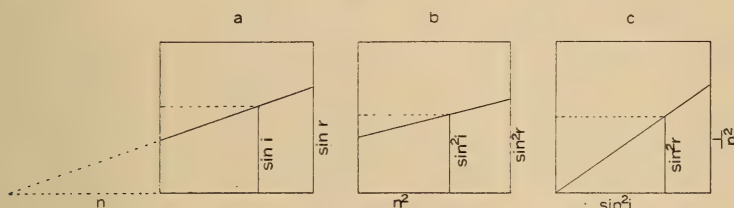
It is of interest to note that, in Plate II, the distance between $i = 0^\circ$ and $i = 5^\circ$ is larger than that of any other 5° interval, while the distance between $i = 85^\circ$ and $i = 90^\circ$ is so small that the intervening degrees cannot be properly represented on the diagram. In Plate III, on the other hand, the distance between successive degrees in the lower part of the projection

* The general principles, on which this construction is based, are discussed at length by C. Runge, in *Graphical Methods*, p. 88-92, 1912.

has been greatly decreased while above 80° the distortion has been materially decreased. In Plate IV the abscissæ are the angles i , the ordinates, the angles r , and the diagonal lines, the refractive indices. This plate has the advantage over Plates II and III in that it covers all possible values of the three variables i , r , and n , but for ordinary work it is less accurate than Plates II and III.

In the preparation of Plates III and IV, Table I of $\sin^2 \alpha$ has been found convenient: The values in this table are given to five places; they were computed, however, to eight places.

FIG. 4.



It has been suggested* that instead of the sine or \sin^2 values the log sine values be plotted. As noted above, however, the logarithmic trigonometric functions show so great distortion that the degrees from 50° to 90° are crowded together and cannot be properly treated graphically except on a very large plot. For graphical purposes, therefore, the direct values of the trigonometric functions are superior to their logarithms.

To use Plate II when i and n are given run the eye along the abscissa until the proper n is reached and then pass up the n ordinate to the required angle i and thence along the diagonal r line to the margin where the r degrees are marked (as indicated on small figure *a* of Plate II). The use of Plates II, III, and IV is illustrated in fig. 4 and is so simple in principle and practice that further explanation is unnecessary.

Plates II and III may also serve in the solution of the minimum deviation prism equation 2 above. The equation is reduced to the proper form by noting that $\frac{B}{2}$, half the prism

angle, corresponds to the angle r of equation 1, while $\frac{A + B}{2}$,

half the sum of the prism angle and minimum deviation angle, corresponds to i of equation 1. Having given r and i find the intersection of the diagonal line r with the horizontal i line, the abscissa of this point being then the desired n value.

* Centralblatt f. Min., 1913, p. 126.

TABLE I.

α	$\sin^2 \alpha$	α	$\sin^2 \alpha$	α	$\sin^2 \alpha$
0°	0.000 00	30°	0.250 00	60°	0.750 00
1	.000 30	1	.265 26	1	.764 96
2	.001 22	2	.280 81	2	.779 60
3	.002 74	3	.296 63	3	.793 89
4	.004 87	4	.312 70	4	.807 83
5	0.007 60	35	0.328 99	65	0.821 39
6	.010 93	6	.345 49	6	.834 57
7	.014 85	7	.362 18	7	.847 33
8	.019 37	8	.379 04	8	.859 67
9	.024 47	9	.396 04	9	.871 57
10	0.030 15	40	0.413 18	70	0.883 02
1	.036 41	1	.430 41	1	.894 01
2	.043 23	2	.447 74	2	.904 51
3	.050 60	3	.465 12	3	.914 52
4	.058 53	4	.482 55	4	.924 02
15	0.066 99	45	0.500 00	75	0.933 01
6	.075 98	6	.517 45	6	.941 47
7	.085 48	7	.534 88	7	.949 40
8	.095 49	8	.552 26	8	.956 77
9	.105 99	9	.569 59	9	.963 59
20	0.116 98	50	0.586 82	80	0.969 85
1	.128 43	1	.603 96	1	.975 53
2	.140 33	2	.620 96	2	.980 63
3	.152 67	3	.637 82	3	.985 15
4	.165 43	4	.654 51	4	.989 07
25	0.178 61	55	0.671 01	85	0.992 40
6	.192 17	6	.687 30	6	.995 13
7	.206 11	7	.703 37	7	.997 26
8	.220 40	8	.719 19	8	.998 78
9	.235 04	9	.734 74	9	.999 70
30	0.250 00	60	0.750 00	90	1.000 00

Plates II and III should furnish refractive index values accurate to about one in the third decimal place.

Examples.—(1) Let $2E = 60^\circ$, the optic axial angle in air of a mineral of refractive index $\beta = 1.535$. Find the true optic axial angle $2V$.

Pass, on Plate II, along the horizontal line, which cuts the ordinate representing the angle E , to its intersection with the

vertical line through the abscissa 1.535 and note that the diagonal line 19° passes through this point. Therefore, $2V = 38^\circ$.

(2) Determine the refractive index of a prism of angle 58° , which shows a minimum deviation angle of 42° .

The refractive index formula (2) reads

$$n = \frac{\sin \frac{58^\circ + 42^\circ}{2}}{\sin \frac{58^\circ}{2}} = \frac{\sin 50^\circ}{\sin 29^\circ}$$

To find n from this formula on either Plate II or III pass along the horizontal line, cutting the ordinate 50, to its intersection with the diagonal line 29 and note that the abscissa at this point is 1.580, the desired refractive index.

Birefringence formulas (Plate V).—The standard exact equation between the refractive indices of a section whose normal includes the angles, ϑ and ϑ' , with the two optic axes is

$$\frac{1}{a'^2} - \frac{1}{\gamma'^2} = \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right) \sin \vartheta, \sin \vartheta'. \quad (3)$$

This equation contains the squares of the reciprocals of the refractive indices, the computation of which is tedious and time-consuming. To obviate this part of the computation, I have computed Table 2 (each value was computed to eight places, only six of which, however, are listed), in which the value of $\frac{1}{n^2}$ is given for all values of n between 1.400 and 2.480;

within these limits the refractive indices of practically all minerals are included. The table is also intended for use in the computation of the optic axial angle from the three refractive indices (equation 5).

In order to prepare a proper graphical plot suitable for all possible values it has been found expedient to express the

fraction $\frac{\frac{1}{a'^2} - \frac{1}{\gamma'^2}}{\frac{1}{a^2} - \frac{1}{\gamma^2}}$ as a percentage—to ascertain, in short,

what percentage $\frac{1}{a'^2} - \frac{1}{\gamma'^2}$ is of $\frac{1}{a^2} - \frac{1}{\gamma^2}$. The same holds true when the approximate equation 4 is used. Having given the differences $\frac{1}{a'^2} - \frac{1}{\gamma'^2}$ and $\frac{1}{a^2} - \frac{1}{\gamma^2}$ or $\gamma' - a'$ and $\gamma - a$,

TABLE II.

n	$1/n^2$	n	$1/n^2$	n	$1/n^2$
1·400	0·510 204	1·440	0·482 253	1·480	0·456 538
1	·509 476	1	·481 584	1	·455 921
2	·508 749	2	·480 916	2	·455 306
3	·508 024	3	·480 250	3	·454 692
4	·507 301	4	·479 585	4	·454 080
1·405	0·506 579	1·445	0·478 921	1·485	0·453 468
6	·505 859	6	·478 259	6	·452 858
7	·505 340	7	·477 598	7	·452 249
8	·504 423	8	·476 939	8	·451 642
9	·503 707	9	·476 281	9	·451 035
1·410	0·502 993	1·450	0·475 624	1·490	0·450 430
1	·502 280	1	·474 969	1	·449 826
2	·501 569	2	·474 315	2	·449 223
3	·500 859	3	·473 662	3	·448 622
4	·500 151	4	·473 012	4	·448 021
1·415	0·499 444	1·455	0·472 361	1·495	0·447 422
6	·498 739	6	·471 712	6	·446 824
7	·498 035	7	·471 065	7	·446 228
8	·497 333	8	·470 419	8	·445 632
9	·496 633	9	·469 774	9	·445 038
1·420	0·495 933	1·460	0·469 131	1·500	0·444 444
1	·495 236	1	·468 489	1	·443 852
2	·494 539	2	·467 849	2	·443 262
3	·493 844	3	·467 209	3	·442 672
4	·493 151	4	·466 571	4	·442 084
1·425	0·492 459	1·465	0·465 934	1·505	0·441 496
6	·491 769	6	·465 299	6	·440 910
7	·491 080	7	·464 665	7	·440 325
8	·490 392	8	·464 033	8	·439 741
9	·489 706	9	·463 400	9	·439 159
1·430	0·489 021	1·470	0·462 770	1·510	0·438 577
1	·488 338	1	·462 141	1	·437 997
2	·487 656	2	·461 513	2	·437 418
3	·486 976	3	·460 887	3	·436 840
4	·486 297	4	·460 262	4	·436 263
1·435	0·485 620	1·475	0·459 638	1·515	0·435 687
6	·484 943	6	·459 015	6	·435 113
7	·484 269	7	·458 394	7	·434 539
8	·483 595	8	·457 774	8	·433 967
9	·482 924	9	·457 155	9	·433 396
1·440	0·482 253	1·480	0·456 538	1·520	0·432 825

TABLE II.—*Continued.*

n	$1/n^2$	n	$1/n^2$	n	$1/n^2$
1.520	0.432 825	1.560	0.410 914	1.600	0.390 625
1	.432 257	1	.410 388	1	.390 137
2	.431 689	2	.409 862	2	.389 650
3	.431 122	3	.409 338	3	.389 164
4	.430 556	4	.408 815	4	.388 679
1.525	0.429 992	1.565	0.408 293	1.605	0.388 195
6	.429 429	6	.407 771	6	.387 712
7	.428 866	7	.407 251	7	.387 229
8	.428 305	8	.406 732	8	.386 748
9	.427 745	9	.406 213	9	.386 267
1.530	0.427 186	1.570	0.405 696	1.610	0.385 788
1	.426 627	1	.405 180	1	.385 309
2	.426 071	2	.404 665	2	.384 831
3	.425 516	3	.404 150	3	.384 354
4	.424 961	4	.403 637	4	.383 878
1.535	0.424 408	1.575	0.403 125	1.615	0.383 403
6	.423 855	6	.402 613	6	.382 928
7	.423 304	7	.402 103	7	.382 455
8	.422 754	8	.401 593	8	.381 982
9	.422 204	9	.401 084	9	.381 510
1.540	0.421 656	1.580	0.400 577	1.620	0.381 039
1	.421 109	1	.400 070	1	.380 570
2	.420 563	2	.399 565	2	.380 101
3	.420 018	3	.399 060	3	.379 632
4	.419 474	4	.398 557	4	.379 165
1.545	0.418 932	1.585	0.398 054	1.625	0.378 698
6	.418 390	6	.397 552	6	.378 233
7	.417 849	7	.397 051	7	.377 768
8	.417 309	8	.396 551	8	.377 304
9	.416 771	9	.396 052	9	.376 841
1.550	0.416 233	1.590	0.395 554	1.630	0.376 378
1	.415 697	1	.395 057	1	.375 917
2	.415 161	2	.394 561	2	.375 457
3	.414 627	3	.394 066	3	.374 997
4	.414 093	4	.393 572	4	.374 538
1.555	0.413 561	1.595	0.393 078	1.635	0.374 080
6	.413 030	6	.392 586	6	.373 623
7	.412 499	7	.392 094	7	.373 167
8	.411 970	8	.391 604	8	.372 711
9	.411 441	9	.391 114	9	.372 256
1.560	0.410 914	1.600	0.390 625	1.640	0.371 803

TABLE II.—Continued.

<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$
1.640	0.371 803	1.680	0.354 308	1.720	0.338 021
1	.371 350	1	.353 887	1	.337 628
2	.370 897	2	.353 466	2	.337 236
3	.370 446	3	.353 046	3	.336 845
4	.369 996	4	.352 627	4	.336 454
1.645	0.369 546	1.685	0.352 209	1.725	0.336 064
6	.369 097	6	.351 791	6	.335 675
7	.368 649	7	.351 374	7	.335 286
8	.368 202	8	.350 958	8	.334 898
9	.367 755	9	.350 543	9	.334 511
1.650	0.367 309	1.690	0.350 128	1.730	0.334 124
1	.366 865	1	.349 714	1	.333 738
2	.366 421	2	.349 301	2	.333 353
3	.365 978	3	.348 888	3	.332 968
4	.365 535	4	.348 476	4	.332 585
1.655	0.365 094	1.695	0.348 065	1.735	0.332 201
6	.364 653	6	.347 655	6	.331 819
7	.364 213	7	.347 245	7	.331 437
8	.363 774	8	.346 836	8	.331 055
9	.363 335	9	.346 428	9	.330 675
1.660	0.362 897	1.700	0.346 021	1.740	0.330 295
1	.362 461	1	.345 614	1	.329 915
2	.362 025	2	.345 208	2	.329 537
3	.361 589	3	.344 803	3	.329 159
4	.361 155	4	.344 398	4	.328 781
1.665	0.360 721	1.705	0.343 995	1.745	0.328 405
6	.360 288	6	.343 592	6	.328 029
7	.359 856	7	.343 189	7	.327 653
8	.359 425	8	.342 787	8	.327 278
9	.358 994	9	.342 386	9	.326 904
1.670	0.358 564	1.710	0.341 986	1.750	0.326 531
1	.358 135	1	.341 586	1	.326 158
2	.357 707	2	.341 187	2	.325 786
3	.357 280	3	.340 789	3	.325 414
4	.356 853	4	.340 392	4	.325 043
1.675	0.356 427	1.715	0.339 995	1.755	0.324 673
6	.356 002	6	.339 598	6	.324 303
7	.355 577	7	.339 203	7	.323 934
8	.355 154	8	.338 808	8	.323 566
9	.354 731	9	.338 414	9	.323 198
1.680	0.354 308	1.720	0.338 021	1.760	0.322 831

TABLE II.—*Continued.*

<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$
1.760	0.322 831	1.800	0.308 642	1.840	0.295 369
1	.322 464	1	.308 299	1	.295 048
2	.322 098	2	.307 957	2	.294 728
3	.321 733	3	.307 616	3	.294 408
4	.321 368	4	.307 275	4	.294 089
1.765	0.321 004	1.805	0.306 935	1.845	0.293 770
6	.320 641	6	.306 595	6	.293 452
7	.320 278	7	.306 255	7	.293 134
8	.319 916	8	.305 917	8	.292 817
9	.319 554	9	.305 579	9	.292 500
1.770	0.319 193	1.810	0.305 241	1.850	0.292 184
1	.318 833	1	.304 904	1	.291 869
2	.318 473	2	.304 568	2	.291 553
3	.318 114	3	.304 232	3	.291 239
4	.317 755	4	.303 896	4	.290 925
1.775	0.317 397	1.815	0.303 561	1.855	0.290 611
6	.317 040	6	.303 227	6	.290 298
7	.316 683	7	.302 894	7	.289 986
8	.316 327	8	.302 561	8	.289 673
9	.315 972	9	.302 228	9	.289 362
1.780	0.315 617	1.820	0.301 896	1.860	0.289 051
1	.315 262	1	.301 564	1	.288 740
2	.314 909	2	.301 233	2	.288 430
3	.314 556	3	.300 903	3	.288 121
4	.314 203	4	.300 573	4	.287 812
1.785	0.313 852	1.825	0.300 244	1.865	0.287 503
6	.313 501	6	.299 915	6	.287 195
7	.313 150	7	.299 587	7	.286 887
8	.312 799	8	.299 259	8	.286 580
9	.312 449	9	.298 932	9	.286 274
1.790	0.312 100	1.830	0.298 606	1.870	0.285 968
1	.311 752	1	.298 279	1	.285 662
2	.311 404	2	.297 954	2	.285 357
3	.311 057	3	.297 629	3	.285 052
4	.310 710	4	.297 305	4	.284 748
1.795	0.310 364	1.835	0.296 981	1.875	0.284 444
6	.310 018	6	.296 657	6	.284 141
7	.309 674	7	.296 334	7	.283 839
8	.309 329	8	.296 012	8	.283 538
9	.308 985	9	.295 690	9	.283 235
1.800	0.308 642	1.840	0.295 369	1.880	0.282 933

TABLE II.—Continued.

<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$
1.880	0.282 933	1.920	0.271 267	1.960	0.260 308
1	.282 633	1	.270 985	1	.260 043
2	.282 333	2	.270 703	2	.259 778
3	.282 033	3	.270 421	3	.259 513
4	.281 733	4	.270 140	4	.259 249
1.885	0.281 434	1.925	0.269 860	1.965	0.258 985
6	.281 136	6	.269 580	6	.258 722
7	.280 838	7	.269 300	7	.258 459
8	.280 541	8	.269 021	8	.258 196
9	.280 244	9	.268 742	9	.257 934
1.890	0.279 947	1.930	0.268 464	1.970	0.257 672
1	.279 651	1	.268 186	1	.257 411
2	.279 356	2	.267 908	2	.257 150
3	.279 061	3	.267 631	3	.256 889
4	.278 766	4	.267 354	4	.256 629
1.895	0.278 472	1.935	0.267 078	1.975	0.256 369
6	.278 178	6	.266 802	6	.256 110
7	.277 885	7	.266 527	7	.255 851
8	.277 592	8	.266 252	8	.255 592
9	.277 300	9	.265 977	9	.255 334
1.900	0.277 008	1.940	0.265 703	1.980	0.255 076
1	.276 717	1	.265 429	1	.254 819
2	.276 426	2	.265 156	2	.254 562
3	.276 136	3	.264 883	3	.254 305
4	.275 846	4	.264 611	4	.254 049
1.905	0.275 556	1.945	0.264 339	1.985	0.253 793
6	.275 267	6	.264 067	6	.253 537
7	.274 979	7	.263 796	7	.253 282
8	.274 691	8	.263 525	8	.253 027
9	.274 403	9	.263 255	9	.252 773
1.910	0.274 115	1.950	0.262 985	1.990	0.252 519
1	.273 829	1	.262 715	1	.252 265
2	.273 542	2	.262 446	2	.252 012
3	.273 256	3	.262 177	3	.251 759
4	.272 971	4	.261 909	4	.251 507
1.915	0.272 686	1.955	0.261 642	1.995	0.251 255
6	.272 401	6	.261 374	6	.251 003
7	.272 117	7	.261 107	7	.250 752
8	.271 833	8	.260 840	8	.250 501
9	.271 550	9	.260 574	9	.250 250
1.920	0.271 267	1.960	0.260 308	2.000	0.250 000

TABLE II.—Continued.

n	$1/n^2$	n	$1/n^2$	n	$1/n^2$
2·000	0·250 000	2·040	0·240 292	2·080	0·231 139
1	·249 750	1	·240 057	1	·230 917
2	·249 501	2	·239 822	2	·230 695
3	·249 252	3	·239 587	3	·230 474
4	·249 003	4	·239 353	4	·230 253
2·005	0·248 755	2·045	0·239 119	2·085	0·230 032
6	·248 507	6	·238 885	6	·229 811
7	·248 259	7	·238 652	7	·229 591
8	·248 012	8	·238 419	8	·229 371
9	·247 765	9	·238 186	9	·229 152
2·010	0·247 519	2·050	0·237 954	2·090	0·228 932
1	·247 273	1	·237 722	1	·228 714
2	·247 027	2	·237 490	2	·228 495
3	·246 781	3	·237 259	3	·228 277
4	·246 536	4	·237 028	4	·228 059
2·015	0·246 292	2·055	0·236 797	2·095	0·227 841
6	·246 048	6	·236 567	6	·227 624
7	·245 804	7	·236 337	7	·227 407
8	·245 560	8	·236 107	8	·227 190
9	·245 317	9	·235 878	9	·226 974
2·020	0·245 074	2·060	0·235 649	2·100	0·226 757
1	·244 832	1	·235 420	1	·226 542
2	·244 590	2	·235 192	2	·226 326
3	·244 348	3	·234 964	3	·226 111
4	·244 106	4	·234 736	4	·225 896
2·025	0·243 865	2·065	0·234 509	2·105	0·225 681
6	·243 624	6	·234 282	6	·225 467
7	·243 384	7	·234 056	7	·225 253
8	·243 144	8	·233 829	8	·225 040
9	·242 904	9	·233 603	9	·224 826
2·030	0·242 665	2·070	0·233 378	2·110	0·224 613
1	·242 427	1	·233 152	1	·224 400
2	·242 188	2	·232 927	2	·224 188
3	·241 950	3	·232 703	3	·223 976
4	·241 712	4	·232 478	4	·223 764
2·035	0·241 475	2·075	0·232 254	2·115	0·223 552
6	·241 237	6	·232 031	6	·223 341
7	·241 001	7	·231 807	7	·223 130
8	·240 764	8	·231 584	8	·222 920
9	·240 528	9	·231 361	9	·222 709
2·040	0·240 292	2·080	0·231 139	2·120	0·222 499

TABLE II.—Continued.

<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$
2·120	0·222 499	2·160	0·214 335	2·200	0·206 612
1	·222 289	1	·214 136	1	·206 424
2	·222 080	2	·213 938	2	·206 236
3	·221 871	3	·213 741	3	·206 049
4	·221 662	4	·213 543	4	·205 862
2·125	0·221 453	2·165	0·213 346	2·205	0·205 676
6	·221 245	6	·213 149	6	·205 489
7	·221 037	7	·212 952	7	·205 303
8	·220 829	8	·212 756	8	·205 117
9	·220 622	9	·212 560	9	·204 931
2·130	0·220 415	2·170	0·212 364	2·210	0·204 746
1	·220 208	1	·212 168	1	·204 561
2	·220 002	2	·211 973	2	·204 376
3	·219 795	3	·211 778	3	·204 191
4	·219 589	4	·211 583	4	·204 007
2·135	0·219 384	2·175	0·211 389	2·215	0·203 823
6	·219 178	6	·211 194	6	·203 639
7	·218 973	7	·211 000	7	·203 455
8	·218 768	8	·210 807	8	·203 272
9	·218 564	9	·210 613	9	·203 089
2·140	0·218 360	2·180	0·210 420	2·220	0·202 906
1	·218 156	1	·210 227	1	·202 723
2	·217 952	2	·210 034	2	·202 541
3	·217 749	3	·209 842	3	·202 358
4	·217 546	4	·209 650	4	·202 176
2·145	0·217 343	2·185	0·209 458	2·225	0·201 995
6	·217 140	6	·209 267	6	·201 813
7	·216 938	7	·209 075	7	·201 632
8	·216 736	8	·208 884	8	·201 451
9	·216 535	9	·208 693	9	·201 270
2·150	0·216 333	2·190	0·208 503	2·230	0·201 090
1	·216 132	1	·208 312	1	·200 910
2	·215 931	2	·208 122	2	·200 730
3	·215 731	3	·207 933	3	·200 550
4	·215 531	4	·207 743	4	·200 370
2·155	0·215 331	2·195	0·207 554	2·235	0·200 191
6	·215 131	6	·207 365	6	·200 012
7	·214 931	7	·207 176	7	·199 833
8	·214 732	8	·206 988	8	·199 655
9	·214 533	9	·206 800	9	·199 477
2·160	0·214 335	2·200	0·206 612	2·240	0·199 298

TABLE II.—Continued.

n	$1/n^2$	n	$1/n^2$	n	$1/n^2$
2.240	0.199 298	2.280	0.192 367	2.320	0.185 791
1	.199 121	1	.192 198	1	.185 631
2	.198 943	2	.192 030	2	.185 471
3	.198 766	3	.191 862	3	.185 311
4	.198 599	4	.191 694	4	.185 152
2.245	0.198 412	2.285	0.191 526	2.325	0.184 993
6	.198 235	6	.191 358	6	.184 834
7	.198 059	7	.191 191	7	.184 675
8	.197 883	8	.191 024	8	.184 516
9	.197 007	9	.190 857	9	.184 358
2.250	0.197 531	2.290	0.190 690	2.330	0.184 199
1	.197 355	1	.190 524	1	.184 041
2	.197 180	2	.190 358	2	.183 884
3	.197 005	3	.190 192	3	.183 726
4	.196 830	4	.190 026	4	.183 569
2.255	0.196 656	2.295	0.189 861	2.335	0.183 411
6	.196 482	6	.189 695	6	.183 254
7	.196 308	7	.189 530	7	.183 098
8	.196 134	8	.189 365	8	.182 941
9	.195 960	9	.189 200	9	.182 785
2.260	0.195 787	2.300	0.189 036	2.340	0.182 628
1	.195 614	1	.188 872	1	.182 472
2	.195 441	2	.188 708	2	.182 317
3	.195 268	3	.188 544	3	.182 161
4	.195 096	4	.188 380	4	.182 006
2.265	0.194 923	2.305	0.188 217	2.345	0.181 850
6	.194 751	6	.188 054	6	.181 695
7	.194 579	7	.187 891	7	.181 541
8	.194 408	8	.187 728	8	.181 386
9	.194 237	9	.187 565	9	.181 232
2.270	0.194 065	2.310	0.187 403	2.350	0.181 077
1	.193 895	1	.187 241	1	.180 924
2	.193 724	2	.187 079	2	.180 770
3	.193 554	3	.186 917	3	.180 616
4	.193 383	4	.186 755	4	.180 463
2.275	0.193 213	2.315	0.186 594	2.355	0.180 309
6	.193 044	6	.186 433	6	.180 156
7	.192 874	7	.186 272	7	.180 003
8	.192 705	8	.186 111	8	.179 851
9	.192 536	9	.185 951	9	.179 698
2.280	0.192 367	2.320	0.185 791	2.360	0.179 546

TABLE II.—*Concluded.*

<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$	<i>n</i>	$1/n^2$
2·360	0·179 546	2·400	0·173 611	2·440	0·167 966
1	·179 394	1	·173 467	1	·167 828
2	·179 242	2	·173 322	2	·167 691
3	·179 091	3	·173 178	3	·167 553
4	·178 939	4	·173 034	4	·167 416
2·365	0·178 788	2·405	0·172 890	2·445	0·167 279
6	·178 637	6	·172 746	6	·167 143
7	·178 486	7	·172 603	7	·167 006
8	·178 335	8	·172 459	8	·166 870
9	·178 185	9	·172 316	9	·166 733
2·370	0·178 034	2·410	0·172 173	2·450	0·166 597
1	·177 884	1	·172 031	1	·166 461
2	·177 734	2	·171 888	2	·166 326
3	·177 584	3	·171 746	3	·166 190
4	·177 435	4	·171 603	4	·166 055
2·375	0·177 285	2·415	0·171 461	2·455	0·165 919
6	·177 136	6	·171 319	6	·165 784
7	·176 987	7	·171 178	7	·165 649
8	·176 838	8	·171 036	8	·165 515
9	·176 690	9	·170 895	9	·165 380
2·380	0·176 541	2·420	0·170 753	2·460	0·165 246
1	·176 393	1	·170 612	1	·165 111
2	·176 245	2	·170 472	2	·164 977
3	·176 097	3	·170 331	3	·164 843
4	·175 949	4	·170 190	4	·164 710
2·385	0·175 802	2·425	0·170 050	2·465	0·164 576
6	·175 654	6	·169 910	6	·164 442
7	·175 507	7	·169 770	7	·164 309
8	·175 360	8	·169 630	8	·164 176
9	·175 214	9	·169 490	9	·164 043
2·390	0·175 067	2·430	0·169 351	2·470	0·163 910
1	·174 921	1	·169 212	1	·163 778
2	·174 774	2	·169 073	2	·163 645
3	·174 628	3	·168 934	3	·163 513
4	·174 482	4	·168 795	4	·163 381
2·395	0·174 337	2·435	0·168 656	2·475	0·163 249
6	·174 191	6	·168 518	6	·163 117
7	·174 046	7	·168 379	7	·162 985
8	·173 901	8	·168 241	8	·162 854
9	·173 756	9	·168 103	9	·162 722
2·400	0·173 611	2·440	0·167 966	2·480	0·162 591

it is not actually necessary to compute the percentage, as this can be done graphically on Plate VI, which is intended primarily for the solution of equation 5, but which serves equally well for this purpose.

Examples.—Solve equation 3 for a section of the mineral aragonite, the normal of the section to include the angles, $\vartheta' = 37^\circ$ and $\vartheta = 57^\circ$, with the two optic axes. The principal refractive indices of aragonite are, $a = 1.530$, $\beta = 1.682$, and $\gamma = 1.686$.

From Plate V we find, by passing along the abscissa axis to $\vartheta = 57^\circ$ and then up along the vertical ordinate to the diagonal line, $\vartheta' = 37^\circ$, that

$$\frac{\frac{1}{a'^2} - \frac{1}{\gamma'^2}}{\frac{1}{a^2} - \frac{1}{\gamma^2}} = 0.505$$

or approximately (equation 4).

$$\frac{\gamma' - a'}{\gamma - a} = 0.505.$$

From Table II, we find that $\frac{1}{a^2} = 0.427186$ and $\frac{1}{\gamma^2} = 0.351791$; hence $\frac{1}{a^2} - \frac{1}{\gamma^2} = 0.075395$. By using this last value and passing along the abscissa axis on Plate VI to $0.075395 \times 1000 = 75.4$ and up the ordinate to the diagonal line $0.505 \times 100 = 50.5$, we find that $\frac{1}{a'^2} - \frac{1}{\gamma'^2} = 0.0381$. Equation 4 above can be solved in similar manner. $\gamma - a = 0.156$ and $\frac{\gamma' - a'}{\gamma - a} = 0.505$. This equation can, however, be put in a better form for graphical solution by Plate VI by first multiplying both numerator and denominator by a whole number, as 500; then $\frac{500}{500} \frac{(\gamma' - a')}{0.156} = \frac{500(\gamma' - a')}{78} = 0.505$. Therefore $500(\gamma' - a') = 39.4$ or $\gamma' - a' = 0.079$.

Equation 4, which is ordinarily used for computing the birefringence, furnishes values which are only approximately correct. In case more accurate values are desired, they can be derived from the standard equations,

$$\frac{1}{a'^2} = \frac{1}{2} \left(\frac{1}{a^2} + \frac{1}{\gamma^2} \right) - \frac{1}{2} \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right) \cos (\vartheta + \vartheta') \quad (21)$$

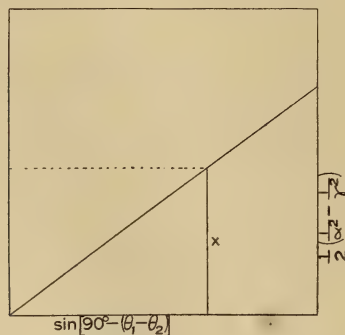
$$\frac{1}{\gamma'^2} = \frac{1}{2} \left(\frac{1}{a^2} + \frac{1}{\gamma^2} \right) - \frac{1}{2} \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right) \cos (\vartheta - \vartheta') \quad (22)$$

The computations required for the solution of these equations can be readily made by use of Table II and Plate VI. The values $\frac{1}{2} \left(\frac{1}{a^2} + \frac{1}{\gamma^2} \right)$ and $\frac{1}{2} \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right)$ can be derived from the data of Table II, and the value of $\frac{1}{2} \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right) \cdot \cos (\vartheta - \vartheta')$ can then be read off directly from Plate V, for this expression can be written

$$\frac{x}{\sin [90 - (\vartheta - \vartheta')]} = \frac{\frac{1}{2} \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right)}{1} \quad (23)$$

The solution of this equation by Plate V is indicated in fig. 5, the principle involved being identical with that of the preced-

FIG. 5.



ing methods. The numerical value of the right-hand side of equation (21) having been thus obtained, the value of a' can be read off directly from Table II. Similarly we find the value of γ' . The difference, $\gamma' - a'$, is then the correct measure of the birefringence for the given section. In minerals of weak birefringence this result is not sensibly different from that derived directly from the simpler equation 4. But in more strongly birefracting substances, this difference between the two results is perceptible and for accurate work equations 21 and 22 should be used.

Example.—To illustrate the course followed in solving equations 21 and 22, let us compute the correct birefringence of the section of aragonite used above (page 527). From the values there given we have

$$\frac{1}{2} \left(\frac{1}{a^2} + \frac{1}{\gamma^2} \right) = 0.389489$$

$$\frac{1}{2} \left(\frac{1}{a^2} - \frac{1}{\gamma^2} \right) = 0.037698$$

and $\vartheta - \vartheta' = 20^\circ$
 $\vartheta + \vartheta' = 94^\circ$

Equations 21 and 22 now read

$$\frac{1}{a'^2} = 0.389489 - 0.037698 \cdot \cos 94^\circ$$

$$\frac{1}{\gamma'^2} = 0.389489 - 0.037698 \cdot \cos 20^\circ$$

The values, $0.037698 \cdot \cos 20^\circ = 0.0355$ and
 $0.037698 \cdot \cos 94^\circ = -0.0027$
 can be read off directly from Plate V. Therefore

$$\frac{1}{a'^2} = 0.389489 + 0.0027 = 0.3921$$

$$\frac{1}{\gamma'^2} = 0.389489 - 0.0355 = 0.3540$$

From Table II we now find that, $\gamma' = 1.681$, and $a' = 1.597$. Accordingly, $\gamma' - a' = 0.084$, a value 0.005 higher than that obtained above (page 527) by means of equation 3 and Plate V. In this particular case the error introduced by the approximate equation is over 5 per cent.

A check on the above values of $\frac{1}{a'^2}$ and $\frac{1}{\gamma'^2}$ can be had by taking their difference $\frac{1}{a'^2} - \frac{1}{\gamma'^2} = 0.0381$, a value identical with that obtained above by use of equation 3.

Optic axial angle formula (Plates VI and VII).—In these plates the variables are, abscissæ $= \frac{1}{a^2} - \frac{1}{\beta^2}$ or $\beta - a$, ordinates $\frac{1}{\beta^2} - \frac{1}{\gamma^2}$ or $\gamma - \beta$ and the diagonal lines $= V$. The drawings are made on the assumption that $\frac{1}{\beta^2} - \frac{1}{\gamma^2} < \frac{1}{a^2} - \frac{1}{\beta^2}$,

and that a is the acute bisectrix; in case $\frac{1}{\beta^2} - \frac{1}{\gamma^2} > \frac{1}{a^2} - \frac{1}{\beta^2}$, γ is the acute bisectrix and the formula should read

$$\tan^2 V_\gamma = \frac{\frac{1}{a^2} - \frac{1}{\beta^2}}{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}$$

The corresponding approximate equations are

$$\tan^2 V_a = \frac{\gamma - \beta}{\beta - a}; \text{ and } \tan^2 V_\gamma = \frac{\beta - a}{\gamma - \beta}$$

To solve the equation for $\tan^2 V_a$ pass up along the ordinate which intersects the abscissa $\frac{1}{a^2} - \frac{1}{\beta^2}$, respectively $(\beta - a)$, to the value $\frac{1}{\beta^2} - \frac{1}{\gamma^2}$, respectively $(\gamma - \beta)$. The diagonal line passing through the point thus obtained is then the desired angle V . (Small figure a , Plate VI.)

It is of interest to note that the ratio $\frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{a^2} - \frac{1}{\beta^2}}$ is always smaller than the ratio $\frac{\gamma - \beta}{\beta - a}$, for $\frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{a^2} - \frac{1}{\beta^2}} = \frac{a\beta + a\gamma}{\gamma\beta + a\gamma} \cdot \frac{\gamma - \beta}{\beta - a}$ and $\frac{a\beta + a\gamma}{\gamma\beta + a\gamma} < 1$.

The effect of substituting the simple relation

$$\tan^2 V_a = \frac{\gamma - \beta}{\beta - a} \text{ for the exact expression } \tan^2 V_a = \frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{a^2} - \frac{1}{\beta^2}}$$

is, therefore, to increase the angle V_a and to obtain an optic axial angle, $2V_a$, which is too large. The error may amount to 2° and over in unfavorable instances. In the case of a mineral in which $\tan^2 V_a = \frac{\gamma - \beta}{\beta - a}$ is slightly > 1 , $2V$, therefore, nearly 90° and the mineral apparently optically +, it may happen that

the exact relation $\tan^2 V_a = \frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{a^2} - \frac{1}{\beta^2}}$ is < 1 and the mineral

is actually optically —, even though the acute bisectrix is direction of stronger birefringence ($\gamma - \beta > \beta - a$). In this instance the ordinary rule that, in a biaxial mineral, the birefringence of a section cut normal to the acute bisectrix is less than that of a section normal to the obtuse bisectrix, is invalid and the reverse is true. Such a reversal of sign can only occur on an optically negative mineral with large optic axial angle, $2V_a$ approximately 90° . The general rule is based on the approximate equation (4) above and is valid for practically all rock-making minerals. To illustrate this inference, let the principal refractive indices of a mineral be $a = 1.511$, $\beta = 1.634$, and $\gamma = 1.764$. In this case $\beta - a = 0.123$ and $\gamma - \beta = 0.130$.

From the approximate formula we have $\tan^2 V_\gamma = \frac{0.123}{0.130}$ from

which we find (Plate VI) $2V_\gamma = 88.4^\circ$. But $1/a^2 = 0.437997$,

$1/\beta^2 = 0.374538$, and $1/\gamma^2 = 0.321368$; $\frac{1}{\beta^2} - \frac{1}{\gamma^2} = 0.053270$,

$\frac{1}{a^2} - \frac{1}{\beta^2} = 0.063459$. Hence, $\tan^2 V_a = \frac{0.053270}{0.063459}$, from which

we find (Plates VI and VII) $2V_a = 85^\circ$. If we were to judge, therefore, from the principal birefringences alone and to apply the above rule, we would consider the mineral optically + with γ , the acute bisectrix, and $2V_\gamma = 88^\circ.4$ from the approximate equation 4, while in reality the mineral is optically — with a , the acute bisectrix, and $2V_a = 85^\circ$. In the examples below this relationship will be clearly shown.

In the preparation of Plate VI the following short table III of the values of $\tan^2 V$ for each degree from 0° to 45° was found useful. The values are listed to five places; they were computed, however, to eight places.

Examples:—(1) What is the optic axial angle of fayalite, whose principal refractive indices are $a = 1.824$, $\beta = 1.864$,

and $\gamma = 1.874$? From Table II we find $\frac{1}{a^2} = 0.300573$, $\frac{1}{\beta^2} =$

0.287812 , and $\frac{1}{\gamma^2} = 0.284748$. Accordingly $\frac{1}{\beta^2} - \frac{1}{\gamma^2} = 0.003064$,

and $\frac{1}{a^2} - \frac{1}{\beta^2} = 0.012761$, and

$$\tan^2 V_a = \frac{0.003064}{0.012761} = \frac{7 \times 0.003064}{7 \times 0.012761} = \frac{0.021448}{0.089327}.$$

TABLE III.

V	$\tan^2 V$	V	$\tan^2 V$	V	$\tan^2 V$
0°	0·000 00	15°	0·071 80	30°	0·333 33
1	·000 30	6	·082 22	1	·361 03
2	·001 22	7	·093 47	2	·390 46
3	·002 75	8	·105 57	3	·421 73
4	·004 89	9	·118 56	4	·454 96
5	0·007 65	20	0·132 47	35	0·490 29
6	·011 05	1	·147 35	6	·527 86
7	·015 08	2	·163 24	7	·567 84
8	·019 75	3	·180 18	8	·610 41
9	·025 09	4	·198 23	8	·655 75
10	0·031 09	25	0·217 44	40	0·704 09
1	·037 78	6	·237 88	1	·755 66
2	·045 18	7	·259 62	2	·810 73
3	·053 30	8	·282 71	3	·869 58
4	·062 16	9	·307 26	4	·932 56
15	0·071 80	30	0·333 33	45	1·000 00

From Plate VI we find with these values $2Va = 52^\circ\cdot2$.

The approximate formula reads $\tan^2 Va = \frac{1\cdot874 - 1\cdot864}{1\cdot864 - 1\cdot824} = \frac{0\cdot010}{0\cdot040}$.

Hence from Plate VI, $2Va = 53^\circ\cdot2$, a value which is 1° too high.

(2) Compute the optic axial angle of petalite from its refractive indices, $\alpha = 1\cdot504$, $\beta = 1\cdot510$, $\gamma = 1\cdot516$. From Table II

we have $\frac{1}{\alpha^2} = 0\cdot442084$, $\frac{1}{\beta^2} = 0\cdot438577$, $\frac{1}{\gamma^2} = 0\cdot435113$; $\frac{1}{\alpha^2} - \frac{1}{\beta^2}$

$= 0\cdot003507$, $\frac{1}{\beta^2} - \frac{1}{\gamma^2} = 0\cdot003464$; $\tan^2 Va = \frac{0\cdot003464}{0\cdot003507}$, from which

we find $2Va = 89^\circ\cdot7$. The mineral is therefore optically negative, if the refractive indices be given correctly. From

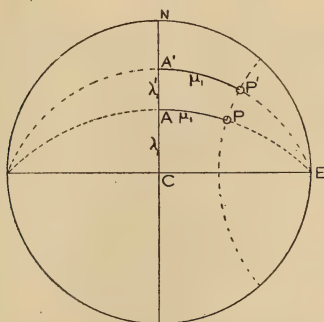
the approximate formula, $\tan^2 V = \frac{\gamma - \beta}{\beta - \alpha} = \frac{0\cdot006}{0\cdot006} = 1$, we are

unable to determine the optical character, for it indicates a value of $2V = 90^\circ$. In the text books the optical character of petalite is stated to be optically + and the optic axial angle, $2V\gamma = 83^\circ$. There is, therefore, a discrepancy between these data which should be investigated.

These examples and the above discussion suffice to show how much information can be readily gathered from the principal refractive indices of a mineral.

Transformation equations for projection work.—In both crystallographical and optical work it is often of advantage to rotate the projection about one or more axes and thus to shift the positions of all directions relative to any specified direction such as the pole of the projection. On rotation of a sphere about an axis, all points on the sphere travel along circles whose planes are normal to the axis of rotation. Thus if we denote the position of a point P by two angles λ_1 and μ_1 , and then rotate the sphere about the horizontal axis OE, the point P travels to P' along the small circle PP', the angle μ_1 remaining unchanged throughout the rotation. By thus expressing the positions of all points by means of the coördinate angles λ_1 and μ_1 , we can rotate the projection about the horizontal

FIG. 6.



axis by simply adding or subtracting the angle of rotation from the angles λ_1 , of all given points, the angles thus obtained locating the positions of all points after the rotation. If now we wish to rotate the projection about the vertical axis ON, it is necessary to ascertain the angles λ_2 , μ_2 , (fig. 6) which correspond to λ_1 , μ_1 of the first position. This is accomplished by means of equations 15 and 16 above, which can be solved by Plates VIII and IX.

Plate VIII is based on equation 15, which can be written

$$\frac{\tan \lambda_2}{1} = \frac{\tan \mu_1}{\sin (90^\circ - \lambda_1)} \quad (15a)$$

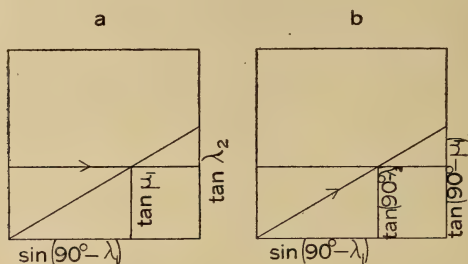
The tangent function extends from 0 to ∞ for values of μ_1 from 0° to 90° . In order to plot the entire function under

these conditions Plate VIII has been so drawn that equation 15a can only be solved graphically for angles $\mu_1 \leq 45^\circ$. For larger angles, equation 15 can be written

$$\frac{\tan(90^\circ - \mu_1)}{1} = \frac{\tan(90^\circ - \lambda_2)}{\sin(90^\circ - \lambda_1)} \quad (15b)$$

This equation can be solved equally well by Plate VIII but only for angles, $\mu_1, \geq 45^\circ$. The two different methods of solutions are illustrated in figures 7a, 7b.

FIG. 7.



This principle of reciprocation is useful in any equation which is to be solved graphically, and in which the values range from 0 to 1 and beyond, thus causing the plot to extend beyond the bounds of the diagram.

The equation

$$\frac{A}{B} = \frac{C}{1}$$

can always be written in the form

$$\frac{\frac{1}{A}}{1} = \frac{\frac{1}{C}}{B}$$

In case A and C are tangent functions as in the present instance, the form of the plate is simple and yet it is competent to solve equation 15 for all values of λ_1 and μ_1 .

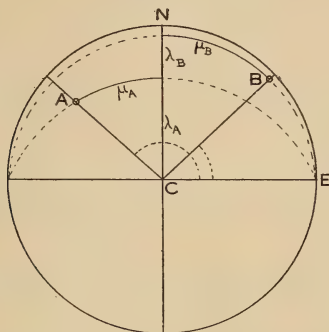
The actual *modus operandi* is best illustrated by an example:

The positions of the two optic axes in oligoclase ($\text{Ab}_{87}\text{An}_{13}$) as determined by Becke are: for optic axis A, $\lambda_{1A} = 67^\circ$ and $\mu_{1A}^* = -46^\circ$; for axis B, $\lambda_{1B} = 85^\circ.5$, and $\mu_{1B} = +47^\circ.5$.

* This angle is sometimes designated ϕ , but in view of the fact that ϕ is used to denote the azimuth angle in crystallography it would seem better to give it the same significance in optical work and to use the letter μ , as above, to designate the latitude angle.

Determine the extinction angles for several sections which are twinned both after the Carlsbad and albite law and show symmetrical extinction angles. From Plate VIII, the required angles can be ascertained without difficulty.

FIG. 8.



In fig. 8 let A and B be the positions of the two optic axes and λ_A , μ_A and λ_B , μ_B , their spherical coördinates. The extinction direction for the direction OC, pole of the projection, can be found by the rule of Fresnel-Biot, which states that the vibration directions of any section bisect the angles between the projections of the optic axes on that section. Thus in fig. 8, the extinction direction bisects the angle BCA. If, therefore, the angles ϕ_A and ϕ_B be computed, then half their sum determines the position of the extinction direction and the angle which this direction includes with the vertical axis ON is the extinction angle. If λ_{1A} and μ_{1A} of the point A be given, the angle ϕ_A is readily calculated by equation 7. Thus, for the axis A, the equation becomes

$$\cot \phi_A = \sin 85^\circ.5 \cot 47^\circ.5.$$

In this case $\mu_{1A} > 45^\circ$; fig. 7b, therefore, should be used. On Plate VIII we find the intersection of the diagonal line $47^\circ.5$ with the ordinate through the abscissa $85^\circ.5$, to be at $\phi_A = 180^\circ - 41.6$. Similarly $\phi_B = 42.4$. Accordingly,

$$\frac{\phi_A + \phi_B}{2} = 90^\circ.4 \text{ and the desired extinction angle is } 90^\circ - 90^\circ.4 = -0^\circ.4.$$

To find now the extinction angle for the section whose normal is in the albite twinning plane (shows symmetrical twinning) and includes an angle of 50° with the pole C (fig. 8), we rotate the projection until this direction coincides with the

pole C; we accomplish this by subtracting 50° from λ_{1A} and λ_{1B} and have the equations to solve

$$\begin{aligned}\cot \phi_A &= \sin 17^\circ \cot (-46^\circ) \\ \cot \phi_B &= \sin 35^\circ \cot 47^\circ\end{aligned}$$

From Plate VII we read off directly

$$\begin{aligned}\phi_A &= 180^\circ - 15^\circ\cdot7 \\ \phi_B &= 28^\circ\cdot1\end{aligned}$$

Therefore, $\frac{\phi_A + \phi_B}{2} = 96^\circ\cdot2$, and the desired extinction angle, $90^\circ - 96^\circ\cdot2 = -6^\circ\cdot2$.

These values might also have been obtained directly by use of the projection plots, but the above method is more accurate and takes less time.

Plate IX is a graphical solution of the general equation

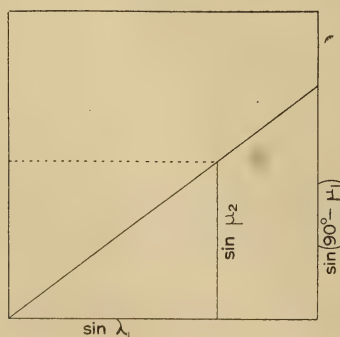
$$\sin A = \sin B \sin C \quad (24)$$

The equations 8, 10, 12, 14, 16, 18 can all be expressed in this form and can therefore all be solved by Plate IX. Thus equation 16 may be written

$$\begin{aligned}\sin \mu_2 &= \sin (90^\circ - \mu_1) \sin \lambda_1, \text{ or} \\ \frac{\sin \mu_2}{\sin \lambda_1} &= \frac{\sin (90^\circ - \mu_1)}{1}\end{aligned} \quad (16a)$$

and solved graphically by Plate IX, as indicated in figure 9.

FIG. 9.



Example.—Let the normal to a given section be located by the two angles $\lambda_1 = 37^\circ$, and $\mu_1 = 41^\circ$; express its position by the two angles λ_2 and μ_2 (see figure 6). Equations 15 and 16 apply to this case.

Thus $\cot \lambda_2 = \cos 37^\circ \cot 41^\circ = \sin (90^\circ - 37^\circ) \cot 41^\circ$.
With these values we find (Plate VIII) $\lambda_2 = 47^\circ.3$.

From equation 16 we have

$$\sin \mu_2 = \sin 37^\circ \cos 41^\circ = \sin 37^\circ \sin (90^\circ - 41^\circ)$$

Solving this equation by Plate IX we obtain

$$\mu_2 = 27^\circ$$

With Plates VIII and IX it is thus possible to pass directly from λ_1, μ_1 to λ_2, μ_2 or to ϕ, ρ without any computation. The above examples are sufficient to indicate the mode of solving the general equations. They do not, however, convey an adequate idea of the wide range of application which these plates have in optical and crystallographical work, especially for verifying computations and the values obtained from projection plots by other graphical methods.

It is important to emphasize the fact that all the transformation equations 7 to 18 can be solved directly by means of Plates VIII and IX, provided proper care be taken to use the complement of the angles wherever necessary. The actual subtraction need not be performed, however, as the complements of all angles are given below and to the right of the actual angles in the two plates.

Projections.

In actual practice nearly all the optical properties of a mineral can be deduced, if the shape and position of its index ellipsoid be known for each given wave length. This index ellipsoid has certain properties which enable the observer to determine the vibration directions and the refractive indices, α' and γ' , of any crystal section; also to ascertain the positions of the two optic axes and the angle between them. By virtue of these properties the observer is able to substitute in place of the several index ellipsoids a single sphere and to operate with that alone. This sphere in turn can be projected and the relations, which obtain on it, can be more or less perfectly represented on a single plane (the plane of projection). Several different projections are in use in optical work at the present time, each of which has its advantages and its weak points. The *orthographic* projection is used chiefly to represent the relations which exist in interference figures, since the interference figures, as they are observed under the microscope, are orthographic projections of the interference phenomena in space. For graphical solutions of optical problems, the stereographic projection is commonly used, the stereographic projection plots of Penfield and Wulff rendering its application direct and accurate. The stereographic projection, however, distorts the hemisphere considerably, the length of an arc of 1° at the mar-

gin of the plot being twice that of 1° at the center of the projection. Now in optical work with projections, the principle emphasized above, that the relative accuracy of the different parts of the plot should be as nearly uniform as possible and comparable to that in nature (in this case, the sphere), is of prime importance, and for this reason several other projections, as the *equidistant* and the *angle* projections, which distort less, are preferable to the stereographic. An angle meridian projection plot, 20^{cm} in diameter, was published by the writer in 1911* and is superior as regards distortion to the other projections which have been suggested. The equidistant and angle meridian projection plots are very similar in form. The details of construction of these projection plots are given in the publication referred to and need not be repeated here.

Summary.

The equations which the petrographer has to solve in connection with his microscopic work are all of the general form, $A = B \cdot C$, in which A , B , and C are variables and usually trigonometric functions. All equations of this form can be solved graphically by straight line plots, provided the functions be plotted directly. The plots are based on the properties of similar triangles and the fact that the above equation can be written in the form $\frac{A}{B} = \frac{C}{1}$. By thus avoiding curves to represent the different values of the equation, the observer not only increases the accuracy of the results obtained but he can also prepare the plots with greater facility and in less time. Although this principle is important, regard should also be had for the distortion introduced, the aim in all graphical solutions being to have the relative accuracy over the entire plot as uniform as possible.

In case the distortion is great for one form of equation, the form may often be changed by introducing some function of both sides of the equation, so that the plot becomes more nearly uniform.

On these principles Plates II to IX have been drawn. With them practically all the equations which the petrographer may encounter in his work can be solved graphically. In the foregoing pages these plates and methods of solution are discussed in detail and illustrated by examples.

In a brief section on projection for use in optical work the principle of minimum distortion is emphasized. The angle and equidistant projection are found to meet these requirements best and are, therefore, recommended for general use in petrographic microscopic work.

* Carnegie Institution of Washington, Pub. 158, 63-67, and Plate XI, 1911.

EXPLANATION OF PLATES II TO IX.

PLATE II. Graphical solution of the refractive index equation $\sin i = n \cdot \sin r$. The ordinates represent the angles i , the abscissæ, the refractive indices, n , and the diagonal lines the angles r . Figure *a* is a graphical solution of the equation $\sin 35^\circ = 1.760 \cdot \sin 19^\circ$.

PLATE III. Graphical solution of the refractive index equation $\sin_2 i = n^2 \sin^2 r$. The ordinates represent the angles i , the abscissæ, the refractive indices, n , and the diagonal lines the angles, r . Figure *a* is a graphical solution of the equation $\sin 56^\circ = 1.710 \cdot \sin 29^\circ$.

PLATE IV. Graphical solution of the refractive index equation $\sin i = n \cdot \sin r$. The abscissæ represent the angles, i , the ordinates, the angles r , and the diagonal lines, the refractive indices n . Figure *a* is a graphical solution of the equation $\sin 53^\circ = 1.700 \cdot \sin 28^\circ$.

PLATE V. Graphical solution of the birefringence equation

$$\frac{1}{a'^2} - \frac{1}{\gamma'^2} = K = \sin \vartheta \cdot \sin \vartheta'$$

$$\frac{1}{a^2} - \frac{1}{\gamma^2}$$

or the approximate equation $\frac{\gamma'}{\gamma} - \frac{a'}{a} = K = \sin \vartheta \cdot \sin \vartheta'$. The abscissæ represent the angles ϑ , the ordinates the values of K , and the diagonal lines the angles ϑ' . Figure *a* is the graphical solution of the equation $0.500 = \sin 43^\circ \cdot \sin 47^\circ$.

PLATE VI. Graphical solution of the optic axial angle equation

$$\tan^2 Va = \frac{1}{\beta^2} - \frac{1}{\gamma^2}$$

$$\frac{1}{a^2} - \frac{1}{\beta^2}$$

; also of the approximate formula $\tan^2 Va = \frac{\gamma - \beta}{\beta - a}$.

In this plate the abscissæ represent $\frac{1}{a^2} - \frac{1}{\beta^2}$, the ordinates $\frac{1}{\beta^2} - \frac{1}{\gamma^2}$ and the diagonal lines the angles Va . Figure *a* is a graphical solution of the equation $\tan^2 40^\circ = \frac{0.043}{0.051}$.

PLATE VII. Graphical solution of the optic axial angle equation

$$\tan Va = \sqrt{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}$$

$$\frac{1}{a^2} - \frac{1}{\beta^2}$$

; also of the approximate equation

$$\tan Va = \sqrt{\frac{\gamma - \beta}{\beta - a}}$$

In this plate the values of $\sqrt{\frac{1}{a^2} - \frac{1}{\beta^2}}$ are plotted along the abscissæ, those of $\sqrt{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}$ along the ordinates, while the diagonal lines represent the angles Va . Figure *a* is a graphical solution of the equation $\tan 38^\circ = \sqrt{\frac{0.025}{0.141}}$.

PLATE VIII. Graphical solution of the transformation equation $\cot A = \sin B \cdot \cot C$. On the plate the angles B have been plotted as abscissæ, the angles C as ordinates, and the angles A as diagonal lines. In case the angle $C > 45^\circ$, the construction indicated in figure *b* should be followed. Figure *a* is a graphical solution of the equation $\cot 40^\circ = \sin 32^\circ \cdot \cot 24^\circ$. Figure *b* is a graphical solution of the equation $\cot 65^\circ = \sin 46^\circ \cdot \cot 57^\circ$.

PLATE IX. Graphical solution of the equation $\sin A = \sin B \cdot \sin C$, the angles A being the ordinates, the angles B the abscissæ, and the angles C the diagonal lines. Figure *a* is a graphical solution of the equation $\sin 24^\circ = \sin 32^\circ \cdot \sin 50^\circ$.

ART. XLVII.—*A Graphical Plot for Use in the Microscopical Determination of the Plagioclase Feldspars*; by FRED. EUGENE WRIGHT. With Plate X.

IN 1901 the writer plotted on a small sheet (12^{cm} x 30^{cm}) of millimeter cross section paper the most important optical properties of the plagioclase feldspars together with their chemical composition. Blue prints of this sheet were used by his students at the Michigan College of Mines and later by some of the members of the Federal Geological Survey. The suggestion has been made at different times that the plot be published, but this has been postponed from time to time, chiefly in the hope of adding to the data of measurement on the plagioclases. It has now been decided to delay no longer but to revise the table so far as possible with the best existing data, and to publish it even though it is not equally correct in all particulars. The effort has been made to give only the more important data, which the working microscopist actually needs.

On Plate X there are represented graphically:

Curves 1. The chemical composition of the plagioclases.

Curve 2. A curve showing the relation between chemical composition and molecular proportions. The use of this curve may be illustrated by an example: Find the molecular percentage of anorthite which the feldspar Ab_xAn_1 contains. This is indicated on curve 2 at the point 33.3 where the horizontal line through the ordinate 2 cuts the curve. Curve 2a is similar to curve 2 except that the unit of its vertical scale is ten times greater. Both curves are parabolas. Similar parabolic curves result when, instead of the molecular percentages of the two end members, the weight percentages are plotted.

The derivation of the equation for the molecular proportion curves is simple. Thus to find the percentage corresponding to the molecular proportions Ab_xAn_1 , we note that in the substance there are x molecules of Ab to every molecule of An. The ratio of one An molecule to the complete molecule is evidently $\frac{1}{1+x}$. The percentage composition is, therefore,

$$y = \frac{100}{1+x}$$

Similarly, if we wish to express the weight percentage of An in the plagioclase Ab_xAn_1 , we note that if the molecular weight of An be m_1 , that of Ab, m_2 , then the total weight of the composition Ab_xAn_1 is $x.m_2 + 1.m_1$, and the percentage composition is

$$y = \frac{m_1}{m_1 + m_2 x} = \frac{1}{1 + \frac{m_2}{m_1} x}$$

which is again a parabola. For convenience in plotting it is an advantage to have x always greater than unity. In case it is less than unity the relation Ab_xAn_1 may be written Ab_1An_z wherein $z > 1$ and a second parabola drawn for which Ab is always unity. Thus Ab_3An_2 may be written $\text{Ab}_{3/2}\text{An}_1$ and the curve An_1 used, while Ab_3An_4 may be written $\text{Ab}_1\text{An}_{4/3}$, to which the curve Ab_1 is applicable.

In the first plot of 1901, the plagioclases were plotted according to weight percentages (the variations in the chemical constituents being then represented by straight lines) and the molecular proportion curves were plotted for this case. In the present plot the plagioclases are plotted in molecular percentages and the molecular proportion curves have been modified accordingly.

Curves 3. Refractive indices α, β, γ , compared with ω and ϵ of quartz.

Curve 4. Optic axial angles.

Curve 5. Extinction angles on 001 (cleavage flake method).

Curve 6. Extinction angles on 010 (cleavage flake method).

Curve 7. Maximum extinction angles in symmetrical zone (sections normal to 010, the plane of albite twinning lamellæ). Statistical method of Michel-Lévy.

Curve 8. Extinction angles on sections normal to α . Fouqué method.

Curves 9. Extinction angles on section normal to γ ; referred in curve 9a to plagioclase lamellæ (010) and in curve 9b to cleavage lines after 001. Fouqué method.

Curve 10. Extinction angles on section normal to β , the optic normal, referred to cleavage after (010) and plagioclase lamellæ.

Curves 11. Curves for combined Carlsbad and albite twinning lamellæ showing symmetrical extinction angles. Michel-Lévy's original chart of these values was based on a formula deduced by Mallard, the values of observation used in the formula having been supplied largely by Michel-Lévy. It has long been known that this chart is seriously in error in certain particulars, errors of 20 per cent in the molecular composition of the plagioclase being possible with certain sets of angles. In view of this fact, the writer has taken the measurements of Becke, Tertsch and one or two by himself on plagioclases of known composition, and calculated the extinction angles for sections in the symmetrical zone, such sections being 10° apart. For each feldspar a set of 18 extinction angles was thus obtained for the poles -90° to $+90^\circ$. These

were plotted to scale and a smooth curve passed through the computed points. After having computed the set of extinction angles for each of the accepted plagioclase feldspars whose optical properties are known with a fair degree of accuracy, the different sets were plotted, each to scale on the ordinate passing through the proper plagioclase composition on the abscissa axis. The variation in the extinction angles of each of the poles was then obtained by passing a curve through the extinction angles for any given pole. On this plot, when completed, there were curves representing the variation in extinction angle with composition for all poles at 10° intervals from $+90^\circ$ to -90° . Now if for any given plagioclase section whose normal is in the plane 010 and includes an angle λ_1 with the pole of the projection (e. g., $+20^\circ$), the extinction angle is δ_1 , then the extinction angle δ_2 of the albite lamellæ in Carlsbad twinning relations to the first set is that of the section whose normal is in the plane 010 and includes an angle $-\lambda_1$ (e. g., -20°) with the pole of the projection. But on the plot prepared as above such extinction angles can be read off directly, and for every extinction angle in the one set the proper extinction angle of the second set at the proper composition can be ascertained. The curves of Plate X were determined in this manner. They are smooth empirical curves passing through known points determined by definite construction from the data of observation. Although similar to the Michel-Lévy curves in form, they are not theoretical curves, but are strictly empirical. Their accuracy depends, therefore, directly on the data of observation. With the accumulation of more precise optical data on the plagioclases, and especially with increase in knowledge of the effect of solid solution with orthoclase, carnegieite or nephelite, and possibly kaliophyllite and other substances, these empirical curves will be changed somewhat. At present, however, they are as accurate as it is possible to draw them from the available data.

A comparison of these curves with the Michel-Lévy set shows on the whole fairly good agreement, although in certain spots the two plots disagree by over 20 per cent. This is especially the case between the plagioclases of the andesine and labradorite groups.

In view of the detailed descriptions of the methods for determining the plagioclase feldspars in all textbooks on microscopic petrography, further explanation of Plate X seems unnecessary.

ART. XLVIII.—*On the Influence of Alcohol and of Cane Sugar upon the Rate of Solution of Cadmium in Dissolved Iodine*; by R. G. VAN NAME and D. U. HILL.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—*eccl.*]

It has been shown by Arrhenius* that the effect of the presence of certain non-electrolytes upon the rate of diffusion of electrolytes may be represented by the empirical equation

$$D = D_0(1 - \frac{a}{2}m)^2,$$

in which D_0 is the diffusion coefficient of the electrolyte in solution in pure water, D the coefficient after the addition of the non-electrolyte, m the molecular concentration of the latter, and a a constant characteristic of the non-electrolyte. When the value of a is known, we may employ this relation, as Jablczynsky† has pointed out, to test the dependence of a given heterogeneous reaction upon the rate of diffusion of a dissolved electrolyte, and thus obtain a test of the validity of the "diffusion theory" in the given case. Since the diffusion theory calls for proportionality between the reaction velocity and the rate of diffusion of the active substance,‡ the effect of a non-electrolyte upon the reaction velocity should be calculable by substituting in the above equation the reaction velocities K and K_0 in place of the corresponding diffusion coefficients.

In a study of the catalysis of chromous chloride at the surface of a sheet of platinum, Jablczynsky showed that the observed effect of ethyl alcohol upon the reaction velocity agreed with that calculated as above, using the value of a determined by Arrhenius. Later, the same author, working with Jablonski,§ obtained a similar result for the effect of alcohol upon the rates of solution of magnesium and of marble in aqueous hydrochloric acid. The reaction velocity was determined in all of these cases by measuring the volume of gas evolved.

In previous papers from this laboratory|| it has been shown that the metals Hg, Cu, Ag, Zn, Cd, Fe, Ni, and Co, all dissolve at the same rate in a solution of iodine in potassium iodide, thus indicating that the diffusion of the iodine, presumably in the form of potassium triiodide, is the determining

* *Zeitschr. phys. Chem.*, x, 51, 1892.

† *Ibid.*, lxiv, 748, 1908.

‡ This is strictly true only when the thickness of the diffusion layer remains unchanged.

§ *Zeitschr. phys. Chem.*, lxxv, 503, 1910.

|| Van Name and Edgar, *this Journal*, (4), xxix, 237; Van Name and Bosworth, *this Journal*, (4), xxxii, 207.

factor. The present article gives the results of a study of the effects of ethyl alcohol and of cane sugar at different concentrations upon the velocity of the reaction between iodine and cadmium. Not only is this reaction especially suitable for the purpose on account of the accuracy of the iodine titration, but it possesses the great advantage over those used by the investigators just mentioned that no gas is evolved.

The last point is of special importance. Since an evolution of gas must rupture the diffusion layer and stir it to some extent with the escape of each gas-bubble, the velocity of such a reaction is by no means as strictly dependent upon the rate of diffusion as when no gas is given off. The number and distribution of the points of bubble formation, for example, are important factors over which the experimenter has little or no control. Reactions in which gases are evolved are, therefore, poorly adapted for quantitative tests of the diffusion theory, a fact which has not thus far received the attention which it deserves.

The apparatus and procedure were practically identical with those employed by Van Name and Bosworth. In brief, it consisted in subjecting to the action of the violently stirred iodine solution circular disks of cadmium, 38.3^{mm} in diameter and 0.5^{mm} thick, which were held in an accurately fixed position relative to the stirrer and to the wall of the containing beaker. The velocity constants were calculated from the equation

$$K = 2.3 \frac{v}{t_2 - t_1} \log \frac{c_1}{c_2},$$

in which v is the volume of the solu-

tion, and c_1 and c_2 the concentrations of iodine (determined by titration) at the beginning and end of the time interval $t_2 - t_1$, (usually ten minutes in length). All solutions were 0.5 molar with respect to potassium iodide, and either 0.01 or 0.001 molar with respect to sulphuric acid, the lower acidity being used when cane sugar was present. The temperature was $25^\circ \pm 0.1^\circ$, and the rate of stirring 200 revolutions per minute. Except where otherwise stated, all details of the manipulation were the same as given in the article just cited. The method there described for determining and applying corrections for the slight variations in the rate of stirring has been systematically employed in the present work, although it was again found that in most cases the corrections had a negligible effect upon the final result. Since the very full data given for some of the experiments in the former paper will serve to illustrate all essential points in the calculations, we shall in general give in this paper only the final corrected series of velocity constants obtained in each experiment.

In the experiments in which ethyl alcohol was present, evaporation from the solution was often much increased, making

it necessary to take this effect into account. As is evident from the equation, loss of solvent (alcohol and water) tends to affect the calculated velocity constants in two ways; by decreasing the volume v , and by increasing the concentration of iodine c . When the last effect is small, however, it may be neutralized or reversed by the evaporation of the iodine itself. Since the corrections to be applied are only small, no appreciable error is introduced by assuming that the free surface of the liquid has a constant area,* and that the volume, therefore,

decreases at a constant rate, or $-\frac{dv}{dt} = \text{Const.}$ The rate of

change in volume was determined either by re-measuring the volume at the end of the experiment or by special blank experiments under like conditions. Knowing the loss per minute, the average volume during each reaction period was calculated by deducting the loss which had occurred up to the middle of that period. The true volumes, so found, have been used in the calculations of all experiments in which the alcohol was 0.5 molar or stronger. Below this concentration the changes in volume due to evaporation were negligibly small.

The effect of evaporation upon the iodine concentration is the resultant of two parts: (I), evaporation of solvent, which can easily be shown to yield the expression $+\frac{dc}{dt} = kc^2$, a reaction of the second order; and (II), evaporation of iodine, which obeys the first order reaction equation $-\frac{dc}{dt} = k'c$.

The changes in concentration resulting from (I) may be calculated from the rate of evaporation. Although this reaction is of a higher order than the main reaction, we have found that in our experiments, owing to the short reaction periods and small changes involved, the resulting change in the value of each velocity constant is, under given conditions, a practically constant amount, which can easily be calculated and subtracted, as a uniform correction, from each velocity constant of a given experiment. To obtain corrections for (II) the evaporation of iodine, blank experiments were made using no cadmium disk, and the constant calculated in the ordinary way. Three such experiments, A, with a solution containing 0.25 molar alcohol; B, with cane sugar, 0.25 molar; and C, without either alcohol or sugar, gave the following results:

A.	K=0.051,	0.032,	0.044,	0.067,	0.070,	average 0.053
B.	K=0.030,	0.024,	0.051,	0.037,	0.055,	" 0.039
C.	K=0.039,	0.044,	0.055,	0.044,	0.077,	" 0.052

* In reality it increases slightly as the volume decreases, owing to the concavity produced by the rotary stirring.

On the basis of these figures we have taken the value -0.05 as the correction for evaporation of iodine. By combining this with the corrections for loss of solvent, determined as above described, we have calculated the following corrections for the net result of evaporation under average atmospheric conditions:

No alcohol	Alcohol, $\frac{1}{4}$ molar	$\frac{1}{2}$ molar	1-molar	2-molar	3-molar
-0.05	-0.04	-0.02	0.00	$+0.04$	$+0.07$

These corrections have been applied in calculating the values of K_2 , the corrected velocity constant, as given in Tables I, II and III.

The cane sugar used was the kind sold in large crystals by confectioners under the name "Rock Candy." To eliminate any possibility of appreciable inversion of the sugar the concentration of sulphuric acid was reduced in the sugar experiments to 0.001 molar. As shown in a previous paper* this change in the acidity should make no appreciable difference in the value of the velocity constant.

The samples of both sugar and alcohol employed were carefully tested as to their effect upon the permanency of the standard of an iodine solution. Neither showed any measurable effect under conditions of concentration comparable with those in the subsequent experiments, even after standing over night.

Experimental Results, and Discussion.

The observed velocity constants are recorded in Tables I, II and III. It will be noticed that in nearly every case the constants show a tendency to diminish in value during the

TABLE I.

No Alcohol or Cane Sugar.

K_1 =velocity constant as observed, uncorrected. K_2 =constant after correction for variation in the rate of stirring and for evaporation. K =most probable value by extrapolation.

									K
1.	$v=$	580	560	540	520	500	480	460 ^{cc}	} 7.30
	$\Delta t=$	10	10	10	10	10	10	10 ^{min}	
	$c=$	42.65	37.60	32.99	28.84	25.09	21.76	18.77	
	$K_1=$	7.30	7.32	7.25	7.24	7.11	7.10	7.11	
	$K_2=$	7.31	7.26	7.20	7.17	7.10	7.04	7.09	} 7.27
2.	$K_2=$	7.29	7.28	7.25	7.24	7.25	7.15	7.24	
3.	$K_2=$	7.24	7.34	7.19	7.14	7.26	7.07	7.21	
4.	$K_2=$	7.07	7.10	7.05	6.93	7.05	6.96	6.88	
5.	$K_2=$	7.11	7.19	7.09	7.04	6.89	7.10	6.83	} 7.14
6.	$K_2=$	7.03	7.16	7.04	7.06	6.95	7.05	6.85	
7.	$K_2=$	7.23	7.19	7.14	7.16	7.09	6.93	7.10	7.22
Average ----									7.21

* This Journal, xxxii, 211.

TABLE II.

Significance of K_1 , K_2 and K as in Table I.

<i>Alcohol $\frac{1}{2}$ molar.</i>							
							K
1. $v =$	580	560	540	520	500	480	460
$K_1 =$	6.90	6.79	6.86	6.83	6.75	6.70	6.75
$K_2 =$	6.85	6.77	6.84	6.80	6.72	6.66	6.72
2. $K_2 =$	7.08	6.93	6.92	6.77	6.81	6.80	6.64
3. $K_2 =$	6.91	6.89	6.66	6.65	6.71	6.60	6.55
4. $K_2 =$	6.98	6.98	6.90	6.74	6.72	6.76	6.77
5. $K_2 =$	6.85	6.87	6.81	6.74	6.69	6.74	6.69
6. $K_2 =$	7.07	7.02	6.94	7.04	6.95	6.90	6.96
7. $K_2 =$	6.92	6.90	7.02	6.89	6.96	6.94	6.89
8. $K_2 =$	6.89	6.78	6.82	6.67	6.68	6.70	6.67
9. $K_2 =$	6.83	6.89	6.82	6.78	6.76	6.82	6.76
<i>Alcohol $\frac{1}{2}$ molar.</i>							
10. $v =$	579.8	559.3	538.7	518.3	497.8	477.3	456.8
$K_1 =$	6.88	6.75	6.69	6.64	6.57	6.57	6.55
$K_2 =$	6.86	6.77	6.63	6.59	6.53	6.55	6.53
11. $K_2 =$	6.71	6.59	6.55	6.47	6.52	6.36	6.36
12. $K_2 =$	---	6.55	6.55	6.45	6.42	6.47	6.44
13. $K_2 =$	6.68	6.63	6.59	6.40	6.38	6.51	6.27
<i>Alcohol 1-molar.</i>							
14. $v =$	579.6	559	538.2	517.5	496.8	476	455.3
$K_1 =$	6.15	5.98	5.73	5.89	6.11	5.90	5.79
$K_2 =$	6.17	5.99	5.72	5.84	6.05	5.89	5.81
15. $K_2 =$	---	6.16	6.08	6.04	6.05	6.07	5.95
16. $K_2 =$	6.19	6.10	6.10	5.99	6.00	5.90	5.98
17. $K_2 =$	6.07	6.12	5.99	5.92	5.92	6.00	5.72
<i>Alcohol 2-molar.</i>							
18. $v =$	579.5	558.5	537.4	516.3	495.2	474.1	453
$K_1 =$	5.19	5.05	5.07	5.09	5.02	5.11	4.97
$K_2 =$	5.23	5.13	5.11	5.15	5.07	5.15	4.97
19. $K_2 =$	5.26	5.04	5.19	5.19	5.23	5.25	4.90
20. $K_2 =$	5.29	5.19	5.10	5.26	5.04	5.07	5.08
21. $K_2 =$	5.20	5.20	---	5.07	5.04	5.12	5.01
22. $K_2 =$	---	5.35	5.20	5.26	5.15	5.23	5.09
<i>Alcohol 3-molar.</i>							
23. $v =$	579	558	536.6	515.2	493.8	472.4	451
$K_1 =$	4.38	4.24	4.34	4.27	4.25	4.28	4.27
$K_2 =$	4.46	4.31	4.41	4.34	4.32	4.35	4.32
24. $K_2 =$	4.36	4.29	4.33	4.38	4.27	4.25	4.30
25. $K_2 =$	4.57	4.36	4.46	4.44	4.42	4.40	4.40
26. $K_2 =$	4.44	4.26	4.27	4.30	4.20	4.26	4.29

TABLE III.

K_2 =velocity constant, corrected for variation in rate of stirring and for evaporation. K =most probable value by extrapolation.

<i>Cane Sugar $\frac{1}{32}$ molar.</i>								K
1. $v =$	580	560	540	520	500	480	460 ^{cc}	
$K_2 =$	6.94	6.82	6.93	6.72	6.80	6.78	6.78	6.90
2. $K_2 =$	6.81	6.76	6.92	6.72	6.74	6.80	6.66	6.82
<i>Cane Sugar $\frac{1}{16}$ molar.</i>								
3. $K_2 =$	6.65	6.78	6.63	6.63	6.48	6.66	6.53	6.71
4. $K_2 =$	6.58	---	6.70	6.57	6.40	6.64	6.63	6.66
<i>Cane Sugar $\frac{1}{8}$ molar.</i>								
5. $K_2 =$	6.32	6.25	6.42	6.26	6.31	6.26	6.25	6.36
6. $K_2 =$	6.23	6.34	6.28	6.28	6.29	6.01	6.30	6.30
7. $K_2 =$	6.18	6.34	6.13	6.32	6.17	6.12	6.15	6.24
<i>Cane Sugar $\frac{3}{16}$ molar.</i>								
8. $K_2 =$	6.01	5.94	5.88	5.99	5.87	5.83	5.81	5.99
<i>Cane Sugar $\frac{1}{2}$ molar.</i>								
9. $K_2 =$	5.52	5.53	5.51	5.44	5.52	5.56	5.44	5.52
10. $K_2 =$	5.49	5.61	5.53	5.54	5.50	5.48	5.46	5.57
11. $K_2 =$	5.42	5.70	5.63	5.50	5.57	5.48	5.55	5.59
<i>Cane Sugar $\frac{1}{2}$ molar.</i>								
12. $K_2 =$	4.27	4.21	4.24	4.05	4.28	4.15	4.13	4.26
13. $K_2 =$	4.26	4.28	4.16	4.21	4.20	4.12	4.16	4.26
<i>Cane Sugar 1-molar.</i>								
14. $K_2 =$	2.20	2.27	2.29	2.27	2.29	2.23	2.26	2.27
15. $K_2 =$	2.24	2.32	2.29	2.35	2.27	2.27	2.30	2.30

course of the experiment. It is almost certain that this is due to a gradual liberation of iodine in the acidified iodide solution, induced by the stirring in contact with air. Strangely enough, this effect, so persistent here, had been negligible or wholly absent in several previous series of experiments under apparently similar conditions, and for this reason the explanation given above was not accepted until after much time had been spent in an unsuccessful effort to find some other adequate one. As it is, no reason is apparent for the more rapid oxidation in the present series of experiments, unless it be justifiable to ascribe it to some slight difference in the purity of the reagents used.

Although the rate of decrease of the constants is of the same order of magnitude in most cases, the presence of this effect

tends to weaken confidence in the mean value of the velocity constant as a proper standard for comparing different experiments. We have therefore preferred to use values determined by graphic extrapolation. The corrected velocity constants of each experiment were plotted against the time and replaced by a smooth curve in the form of a line of very slight curvature, convex upward,* which was then extrapolated back to time zero. The value of the constant for time zero, so fixed, has been taken as representative of the experiment. Although this method fails in some cases to give sharp results, we believe that in general the extrapolated values represent the single experiments more accurately than the averages of their constants.

TABLE IV.
Summary of Velocity Constants.

Non-electrolyte	K observed Average value	Mean of extrapolated values	K calculated by equation of Arrhenius
None	7.11	7.21	(7.21)
Alcohol, 1/4 molar	6.82	6.92	6.99
“ 1/2 “	6.53	6.67	6.77
“ 1 “	5.99	6.12	6.34
“ 2 “	5.16	5.24	5.53
“ 3 “	4.35	4.41	4.78
Cane Sugar, 1/32 m.	6.80	6.87	7.07
“ “ 1/16 “	6.61	6.69	6.94
“ “ 1/8 “	6.25	6.30	6.67
“ “ 1/4 “	5.52	5.56	6.15
“ “ 1/2 “	4.19	4.26	5.17
“ “ 1 “	2.28	2.29	3.47

A summary of the measured velocity constants is given in Table IV, including both the average and the extrapolated values. For reasons given, we shall base all further calculations upon the latter, but the parallelism between the two sets of values shows that this choice is not a matter of much importance, as the general nature of the results would be the same in either case.

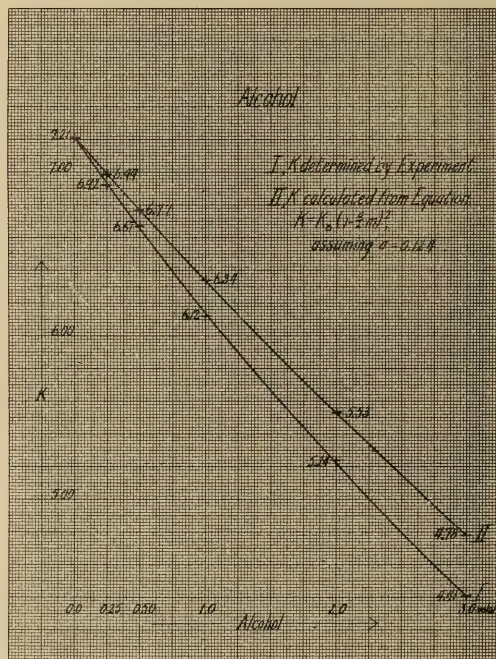
In the last column of Table IV are constants calculated from the equation of Arrhenius, using the values $a = 0.124$ for alcohol, and $a = 0.613$ for sugar. These two values were obtained by averaging (after reducing to 25°) various values of a calculated by Arrhenius† both from his own diffusion measure-

* A simple calculation shows that the constants would lie on a curve of this form if a slight oxidation were the only source of error.

† Zeitschr. phys. Chem., x, 51, 1892.

ments and from those of Lenz.* For the same non-electrolyte the constant a varies but slightly with the nature of the diffusing substance so long as the latter is an electrolyte of simple structure. The value 0.124 for alcohol is the average of fairly concordant determinations with sodium chloride, sodium hydroxide, sodium iodide, potassium iodide, and cadmium iodide, and is therefore probably near the correct value for iodine diffusing

FIG. 1.



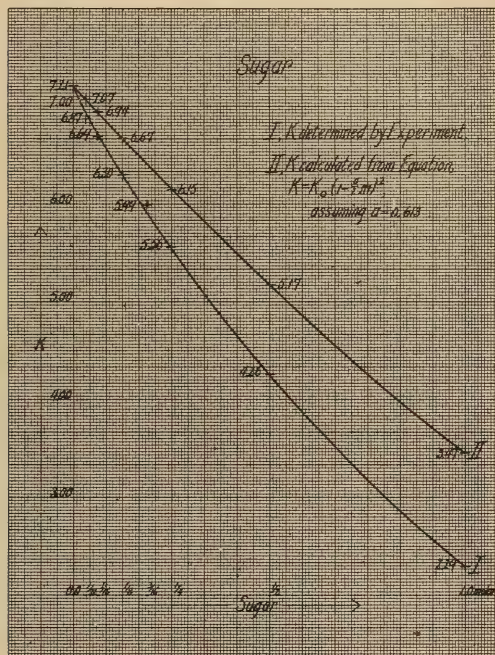
as KI_3 . The value 0.613 for sugar is derived from measurements with sodium chloride and ammonium hydroxide as the diffusing substances. In the absence of any published data concerning measurements of this kind with iodine itself, these values of a may be regarded as the most probable.

A graphical comparison of the calculated with the measured constants is given by figs. 1 and 2. It is evident that the measured values give very regular curves but are lower throughout, both for alcohol and cane sugar, than the calculated values. If, on the other hand, the constant a is calculated from the

* Mémoires de l'Acad. de St. Petersburg (7), xxx, 57, 1882.

observed rates of solution of cadmium we obtain the figures in the middle column of Table V. The calculated values of a diminish with increasing concentration of the non-electrolyte, though much more rapidly with sugar than with alcohol. Nevertheless, by selecting from the series for alcohol the value of a best adapted to the purpose, and with it recalculating K from

FIG. 2.



the equation of Arrhenius, a good agreement with the measured velocity constants is obtained (see Table V, last column). Although the value $a = 0.144$ is higher than would be expected from the diffusion measurements of Arrhenius, it cannot be regarded as an impossible value for the hitherto undetermined effect of alcohol upon the diffusion of potassium triiodide, so that the validity of Arrhenius' equation in this particular case, if not clearly established, is certainly not disproved.

With cane sugar, however, this procedure gives no satisfactory agreement between the observed and calculated results whatever value of a be employed. The value 0.925, from which the results in Table V were calculated, is perhaps as

TABLE V.

	K obs.	<i>a</i> calc.	K calc. <i>a</i> = 0.144
No alcohol or sugar	7.21	----	----
Alcohol 1/4 molar	6.92	0.163	6.95
“ 1/2 “	6.67	0.152	6.71
“ 1 “	6.12	0.157	6.19
“ 2 “	5.24	0.147	5.28
“ 3 “	4.41	0.144	(4.41)
			K calc. <i>a</i> = 0.925
Cane sugar 1/32 molar	6.87	1.53	7.00
“ “ 1/16 “	6.69	1.18	6.80
“ “ 1/8 “	6.30	1.04	6.40
“ “ 1/4 “	5.56	0.975	5.64
“ “ 1/2 “	4.26	0.925	(4.26)
“ “ 1 “	2.29	0.872	2.08

good as any. This, of course, only confirms what was clearly indicated by the nature and magnitude of the variation in the calculated values of *a*.

In short, the effect of cane sugar upon the rate of solution of cadmium appears to be larger, and to increase less rapidly with the concentration, than is called for by Arrhenius' equation, while with alcohol the deviations from the equation are small but probably of the same nature.

These deviations can easily be explained if we admit that a change in the viscosity, under otherwise constant conditions, may alter not only the rate of diffusion but also the thickness of the diffusion layer, the latter effect being, of course, one of which Arrhenius' equation takes no account. As Table VI shows, both alcohol and sugar raised the viscosity of the potassium iodide solution used.

In considering this hypothesis we wish to oppose the view sometimes taken that the diffusion layer consists of liquid which, relatively to the dissolving solid, is nearly or wholly at rest. On the contrary, it is probable that its outer portions possess a very considerable motion relative to the solid, but only in a plane essentially parallel to the surface of the latter, and, therefore, normal to the direction of the concentration slope, so that the rate at which dissolved material is transported across the diffusion layer is not materially affected by the motion of the liquid layer itself. The thickness of this layer is not necessarily constant at a given point on the surface of the solid, but is more probably subject to periodic variations dependent upon the passage of the blades of the stirrer. We are, therefore, to understand as the thick-

ness of the diffusion layer the *average distance* from the surface of the solid at which the stirring effect of the eddies and cross-currents prevailing in the main body of liquid becomes negligible. The relation of this magnitude to the viscosity of the liquid is the question to be considered.

TABLE VI.
Viscosity and Density of Solutions at 25°.

	Viscosity Coefficient	Specific Gravity Water at 25° = 1
No alcohol or sugar	0.00888	1.0606
Alcohol 1/4 molar	0.00903	1.0624
“ 1/2 “	0.00942	1.0592
“ 1 “	0.01024	1.0552
“ 2 “	0.01210	1.0478
“ 3 “	0.01410	1.0416
Cane sugar 1/32 molar	0.00889	1.0675
“ “ 1/16 “	0.00911	1.0717
“ “ 1/8 “	0.00967	1.0799
“ “ 1/4 “	0.01090	1.0963
“ “ 1/2 “	0.01521	1.1368
“ “ 1 “	0.03272	1.2103

The strict mathematical treatment of problems in viscosity, in all but the simplest cases, offers serious difficulties, and would do so in the present instance. On purely logical grounds, however, it seems almost certain that an increase in viscosity, other factors remaining unchanged, would hinder the propagation of the eddies above referred to, and would thus produce an increase in the thickness of the diffusion layer. In reality, a change in the viscosity of a liquid usually involves an appreciable change in its density, and an increase in density, with the resulting increase in the momentum of the moving liquid, should tend to make the eddies more persistent, thus acting, so far as its effect was appreciable, in a direction opposite to that of an increase in viscosity. As a rule, however, the change in density would be small compared with the change in viscosity, and probably of minor importance.

Alcohol in our experiments raised the viscosity and lowered the density of the 0.5 molar potassium iodide solution employed. Cane sugar raised the viscosity by a large and the density by a relatively small amount, an increase of 280 per cent in the former corresponding to an increase of 14 per cent in the latter. Both are clearly cases where an increase rather than a decrease in the thickness of the diffusion layer would be expected. Such an effect would be in the right direction to explain the fact that the depression of the reaction velocity is

larger than would be predicted from the diffusion data, while the entrance of this new factor would account for the observed deviations from the form of Arrhenius' equation.

In general, if one grants the existence of a diffusion layer it is hard to avoid the conclusion that its thickness would vary somewhat with the viscosity. The influence of a variation of this kind seems to be perceptible in the experimental results of this investigation.

Summary.

1. The effect of various concentrations of ethyl alcohol, and of cane sugar, upon the rate of solution of cadmium in an iodine-potassium iodide solution, has been measured at 25°.

2. With alcohol the observed velocity constants agree well with the constants calculated from Arrhenius' equation for the effect of a non-electrolyte upon the diffusion of electrolytes, if an arbitrary though, so far as can be judged by analogy, not impossible value is chosen for the constant a in that equation.

3. With cane sugar the observed results cannot be brought into good agreement with Arrhenius' equation by any value of a .

4. In both cases, but especially in that of the sugar, the depression of the reaction velocity appears to be larger than would be expected from the available diffusion data.

5. The probable effect of an increase in viscosity in increasing the thickness of the diffusion layer is discussed, and is suggested as a possible explanation of the discrepancies.

ART. XLIX.—*Comparative Studies of Magnetic Phenomena.*IV. *Twist in Steel and Nickel Rods due to a Longitudinal Magnetic Field* ;* by S. R. WILLIAMS.

It is a well-known fact that if a ferromagnetic wire or rod is both circularly and longitudinally magnetized it will suffer a twist though no external mechanical force is used. This is known as the Wiedemann† magnetostrictive effect. Wiedemann also found that if an iron rod was first twisted mechanically and then subjected to a longitudinal magnetic field it would also twist mechanically due to the imposed field. This last effect has received very little attention since Wiedemann first discovered it in iron and so far as the author knows no extension of the work has been done on nickel and cobalt. The method used in a former work‡ for photographically registering changes in length and twist due to a magnetic field has been so successful in picking up small details of the variation that it seemed worth while to apply it to this effect, particularly as this special effect found by Wiedemann is superimposed upon the regular effect known as the “Wiedemann effect” and it should be sifted out. As cobalt rods could not be procured, this study deals with an investigation of a dozen steel rods and two nickel rods. Only one set of graphs for the steel rods is shown, as they are typical of the rest.

The literature on this particular subject is very limited. Smith§ records that he observed in the case of one iron rod a twist due to a longitudinal magnetic field, but he merely alludes to it and devotes most of his article to the effect of magnetization upon steel rods possessing “permanent torsional set,” produced at the time the rods were tested. Grösser|| also found that under certain conditions twists in steel rods occurred due to a longitudinal field. His method consisted in setting the rod into torsional vibration and taking the means of a series of amplitudes. From these results he found that the zero points were shifted as the field strength was increased. It is evident from the accompanying graphs, figs. 1 and 2, that a nickel or steel rod which one procures from the open market may show a twist, when magnetized longitudinally.

In a former paper,¶ I have pointed out that under certain conditions one should expect, from the planetesimal theory of magnetism, a twist due to a longitudinal field. The present paper deals with these conditions in steel and nickel rods and is an attempt to find out how conditions favorable for such a twist are brought about.

* Read by title before the Ohio Academy of Science, November, 1912.

† Pogg. Ann., ciii, 571, 1858, 161, 1859. Wiedemann's Elektrizität.

‡ Phys. Rev., xxxiv, 258, April, 1912. § Phil. Mag., xxxii, 385, 1891.

|| Inaug. Diss., Rostock, 1896.

¶ Phys. Rev., abstract, February, 1911.

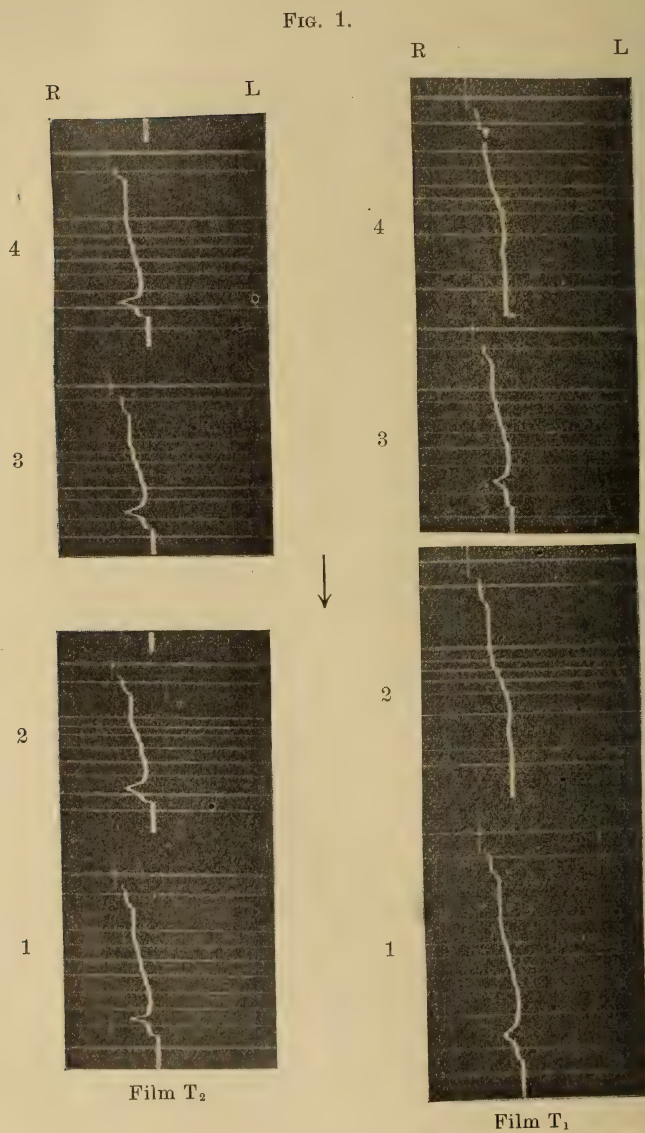
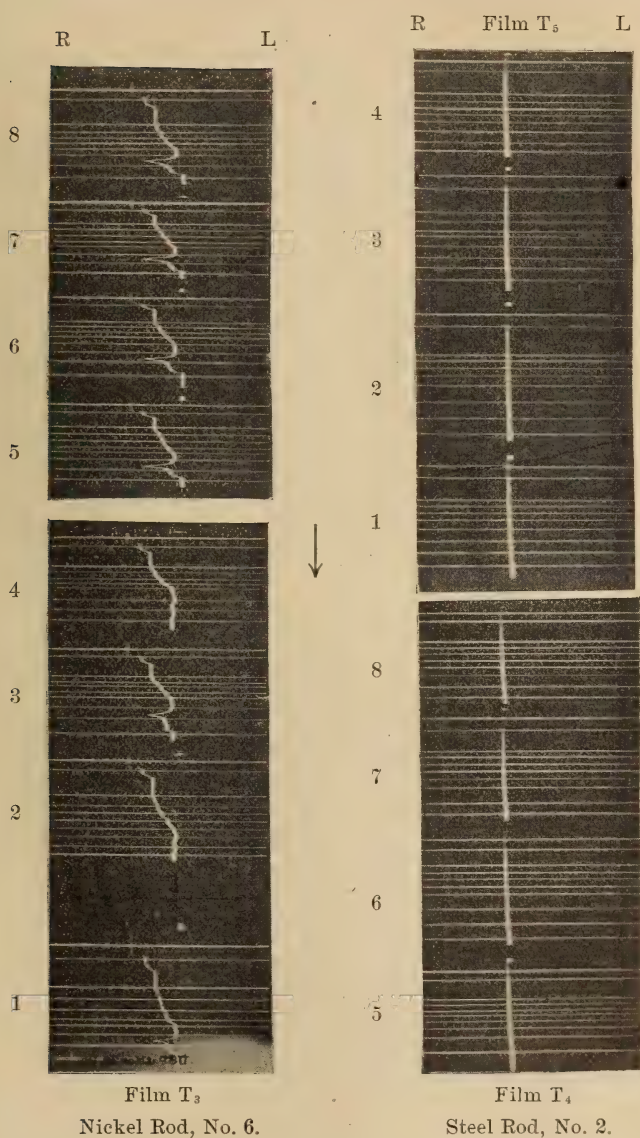


FIG. 1 Nickel Rod, No. 5.

FIG. 2.



METHOD OF TAKING OBSERVATIONS.

The rods used in this work were suspended by the upper end in a vertical solenoid* used in previous investigations. A concave mirror was attached to the lower end, which threw the image of an incandescent filament upon a slit behind which a photographic film moved and on which were traced the deflections of a spot of light:

For graphs 1, 2, 3 and 4, film T_1 , fig. 1, graphs 1, 2, 3 and 4, film T_2 and graphs 5, 6, 7 and 8, film T_3 , fig. 2, the rods were demagnetized before each graph was made; that is, everything being in adjustment a decreasing alternating current was sent through the solenoid and then graph 1 was run off. After the maximum field strength had been attained for graph 1 the field was suddenly broken and the rod again demagnetized by the decreasing alternating current field. Graph 2 was then run off but with the magnetic field in the opposite direction to that of graph 1. This was repeated for graphs 3 and 4. In all cases, odd-numbered graphs are for fields directed upwards in the solenoid while even-numbered graphs have their fields downward. Graphs 1 and 3 are duplicates under the same conditions, which also hold for graphs 2 and 4, 5 and 7, etc. In all of my previous work I have demagnetized in this way before each graph was taken so that the rods would have the same treatment before taking the next graph.

The parallel straight lines in the photographs indicate definite currents flowing in the solenoid. The values of the field strengths for these currents may be obtained from figs. 3 and 4.

I have gone to some length in speaking of the magnetic treatment which these rods received before each graph was made, as an inspection of the curves in figs. 3 and 4 shows that the previous history makes a great difference in the results if one wishes to duplicate them. Graphs 1 and 3 or 2 and 4 in any of the figures show that by similar treatment remarkable duplications may be obtained after a cyclic state has been established.

To show what the effect would be if the rods were not demagnetized, film T_2 , T_3 and graphs 5, 6, 7 and 8 of film T_3 have been added. The field was reversed for each graph just as in the case for the other films, but the demagnetization was omitted. Even for graph 1 a field was previously imposed on the rod opposite to that which it was to have for graph 1. In each case the field was broken suddenly, and, without demagnetization the circuit was reversed for the succeeding graph. Just as in the case of the graphs showing demagnetization so

* Phys. Rev., xxxiv, 258, 1912.

here the odd-numbered graphs are for fields directed upwards, the even-numbered for fields directed downward. Graphs 1 and 3 are duplicates, similarly 2 and 4, etc.

FIG. 3.

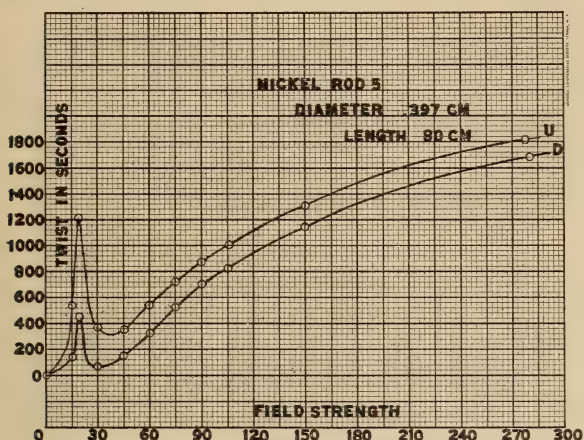
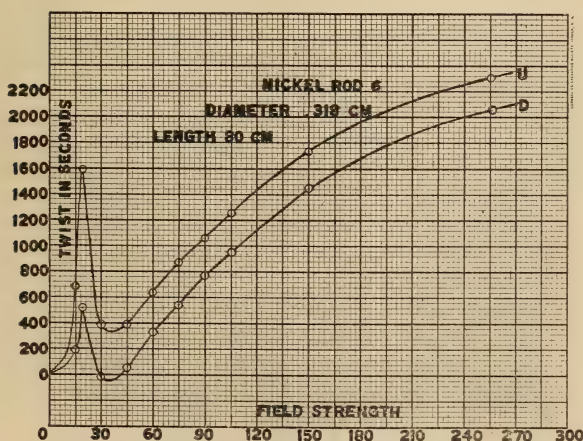


FIG. 4.



The question may be raised as to why these rods were not annealed at the start. My purpose has been to carry out a series of experiments on the same rods and to study different

heat treatments. Once the rods were annealed it would be impossible to come back to the condition they are now in and which from a magnetic standpoint is exceedingly interesting. I want a series of comparative studies on them in their present state.

In the graphs I have indicated the direction of the motion of the films by a long arrow and the twist is marked by R and L to indicate whether the lower end of the rod when viewed from above twisted clockwise or counter clockwise. The photos are shown as though one stood behind a transparent screen and viewed the deflections in that way. The graphs are numbered along the left hand margin of the photos and the letters T_1 , T_2 , T_3 , etc., refer to the way in which the films were catalogued in my collection of films.

DISCUSSION OF RESULTS.

I have spoken of having demagnetized the rods by a decreasing A. C. sent through the solenoid. It was found that no matter which end of the rod was up the rod always showed permanent magnetization downwards after each demagnetization. Not only was this permanent magnetization independent of the end which was up but also it was independent of the direction of the previous magnetic field. In every case the remanent magnetism was directed downwards. If a steel rod is held parallel to the earth's field and tapped with a hammer it will be found to possess a polarity corresponding to the direction of the earth's field. In the shaking up of the elementary magnets, they have settled into alignment under the influence of the earth's field. It would seem that here a similar effect occurred when the elementary magnets were disturbed by the field due to the decreasing alternating current. The effect of this permanent magnetization was eliminated in the final results by taking the mean of the reversed readings.

That the permanent magnetization has much to do with this effect is shown by a comparison of the curves marked U and D for both of the nickel rods, figs. 3 and 4. The rods not demagnetized, (U), show a much larger twist than those, (D), from which at least a part of the permanent magnetization has been removed. This leads to another point, which, so far as I know, is new, viz., that in the magnetostrictive effects we have the analogue of the Von Waltenhofen* phenomenon.

A close inspection of the rods indicated that in the process of drawing they had been given a permanent torsional set and in the case of the nickel rods this was a right-handed twist.

* The data have been collected on this subject and will be presented at a later date.

A sample of the rod was placed in dilute nitric acid and after dissolving for a little while spiral ridges were plainly to be seen running around the samples. This showed that the rods were not homogeneous but in the process of forming had been given a definite helical structure. We know that magnetism produces mechanical strains in ferromagnetic substances and also that mechanical stresses produce changes in magnetic properties. Hence we may expect that in the case of the rods having a definite mechanical structure, as these nickel rods do, a large number of the elementary magnets would have a definite orientation. This may help to increase the permanent magnetism observed in these rods.

Again, if these elementary magnets are elongated as has been suggested and swing from one position of equilibrium to another, then in their swinging they would produce changes in length along the spiral formation of the rod and consequently a twisting due to a longitudinal field. This is in agreement with the original observation of Wiedemann, who found that reversing the direction of the magnetic field did not reverse the direction of twist in rods having permanent torsional set, that is, a change in length along the helix, whether it is due to an up or a down field, produces the same sort of a twist. The conditions, therefore, for a twist due to a longitudinal magnetic field seem to be (1) the presence of a permanent torsional set, either produced at the time the rod was drawn or rolled or else produced by the experimenter as Weidemann and Smith did in their work; or (2) the elementary magnets may be swung into spiral formations by magnetic processes.

In testing about fifteen steel rods for the effect here studied it was quite evident that in some the twist was largely due to a definite setting of the elementary magnets along helical lines in the rod. This is further corroborated by the fact that increased permanent magnetization increased the effect. The initial and final twists for the nickel rods are in a direction to increase still more the permanent torsional set.

These results show that for some specimens of ferromagnetic substances two mechanical effects may occur when a longitudinal magnetic field is imposed upon them, viz., a change in length and a twist. These effects and also other magnetostrictive effects are larger in nickel than in iron or steel. The twist for steel was so small that it was not plotted. The maximum twist shown in fig. 2, film T_4 and T_5 , amounted to about 100 seconds of arc. Following each graph for both the nickel and steel rods, the spot of light was allowed to record the position of deflection when the field was thrown off. This helps to make the twist in the steel rod more apparent. The twists observed in the nickel rods are, as has been said, apparently

due to the orientation of elongated ellipsoids arranged along the lines of permanent torsional set. The first maximum, as will be shown in another paper, occurs at the same field strength as does the maximum elongation in the Joule effect.

The fact that a mechanical effect due to magnetization, as here described, can occur in a rod because somewhere in its history it has suffered some change in its structure, points out very emphatically that one must be very sure how the specimens were prepared, else there can be no way of comparing one observer's results with another and hopeless confusion arises. This, of course, can be overcome by carrying out a comparative study of different magnetic phenomena on the same specimens. This has been the object of these studies.

Physical Laboratory,
Oberlin College, Oberlin, Ohio.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *Hydrides of Boron*.—It has been known for a long time that metallic borides, such as magnesium boride, give off hydrogen containing a hydride or hydrides of boron when treated with acids, as the gas has a strong odor, but the nature of the product has not been known. ALFRED STOCK has now investigated this subject and has obtained the compound B_4H_{10} which boils at $16^\circ C$. and decomposes gradually upon standing, and rapidly upon heating to $100^\circ C$. into hydrogen, another gaseous hydride, B_2H_6 , and solid and liquid hydrides of boron. The latter have not yet been thoroughly investigated, but the compound B_2H_6 has been obtained in a pure condition by condensation with liquid air, whereby the hydrogen mixed with it was removed. The condensed gas boils at $87^\circ C$., and the melting-point of the solid lies below $-140^\circ C$. This gas, B_2H_6 , is much more easily decomposed by water than B_4H_{10} , a fact which accounts for the production of the latter by the action of aqueous acids upon magnesium boride. In view of the existence of liquid and solid hydrides of boron as well as the two gaseous ones that have been investigated, it appears that these compounds may almost approach the hydrocarbons in their complexity.—*Berichte*, xlv, 1959.

H. L. W.

2. *Metallic Beryllium*.—FICHTER and JABLONZYNSKI have prepared this metal by the electrolysis of mixtures of fused sodium and beryllium fluorides. By repeated centrifugation of the im-

pure product in a mixture of ethylene bromide and alcohol, the comparatively light metal was separated from the oxide present as an impurity. The melting-point of the metal is about 1280°C . The fused metal is very hard, scratches glass and is only slightly marked with a file. It is steel-gray in color (not silver-white, as stated by Delray). The specific gravity is 1.842, and the atomic volume 4.94. It resists the action of water, but nitric acid readily dissolves it.—*Berichte*, xlvii, No. 7. H. L. W.

3. *General Chemistry, Theoretical and Applied*; by J. C. BLAKE. 8vo, pp. 417. New York, 1913 (The Macmillan Company. Price \$1.90, net).—This text-book is intended primarily for the use of college students whose study of the subject lasts only one year. While the book contains much chemical information and possesses a number of good features, it does not appear to be an improvement upon most of the many existing books covering nearly the same ground. It is sparsely illustrated, although a few of the illustrations, being copied from standard works, are excellent. There are a good many unsatisfactory statements and too many mistakes in facts. It professes to introduce the subject in a novel way, through thermo-chemistry, and at the start a table of calorific values for the oxidation of a number of metals is given. This does not seem to be enlightening to the student, who may not be supposed to know, as yet, anything about either the metals or their oxides; and, further, while a good many thermo-chemical equations are given through the book, it does not appear that the "calorie" is defined or explained anywhere. Moreover, in the last chapter the statement is made that the calorific value of a coal can be determined by burning it in a calorimeter, but how this is done, or what a calorimeter is, is not explained at all. On the whole, the publication of this book does not seem, to the reviewer, to have been worth while. H. L. W.

4. *A Dictionary of Applied Chemistry*; by SIR EDWARD THORPE, Assisted by Eminent Contributors. Revised and Enlarged Edition. Vol. IV; large 8vo, pp. 727. London, 1913 (Longmans, Green and Co.).—The present volume of this important work of reference covers the portion of the alphabet including OILSTONE and SODA-NITRE. Among the more extensive articles are those on oxygen, ozone, paints, paper, paraffine, petroleum, phenol and its homologues, phosphorus, photography (34 pages), pigments, polarimetry, potassium, pottery and porcelain, proteins, pyrometry, quinoline, quinones, radioactivity, resins, rubber, saponification, sewage, silver, soap, etc. These very excellent and extensive monographs, together with a great many shorter articles, make the volume very attractive and useful. H. L. W.

5. *General and Industrial Organic Chemistry*; by DR. ETTORE MOLINARI, Translated from the Second Enlarged and Revised Italian Edition by THOMAS H. POPE. Large 8vo, pp. 770. Philadelphia, 1913 (P. Blakiston's Son & Co. Price \$6.00).—This is a very noteworthy work, as it is a treatise on general organic chemistry in which not only is the theoretical side considered but

also the practical applications of the science are extensively elaborated. It is the sequel of a similar volume on inorganic chemistry by the same author, which has already been noticed in this department of this Journal, and, like the preceding volume, it is recommended as a very useful and important book of reference and study for chemical students. It contains a vast amount of accurate information in regard to manufacturing operations and statistics of production.

H. L. W.

6. *Chemistry and its Relations to Daily Life*; by LOUIS KAHLBERG and EDWIN B. HART. 12mo, pp. 393. New York, 1913 (The Macmillan Company).—This text-book is intended particularly for the use of students of agriculture and home economics in secondary schools. It does not go very deeply into pure chemistry, but it explains the more fundamental and useful chemical theories and the more important general facts in a very satisfactory manner, and it gives a good exposition of the chemistry of daily life. This seems to be a very suitable book for the perusal of persons, outside of school, who wish to gain an insight into chemistry.

H. L. W.

7. *Studies in Valency*; by F. H. LORING. 12mo, pp. 47. London, 1913 (Simpkins, Marshall, Hamilton, Kent & Co., Ltd. Price 2s. 6d., net).—This little book deals with speculations in regard to variable valency and the relation of valency to the periodic system. These speculations, as far as they are original, do not appear to be important contributions to chemical theory, but they may be of interest to those who make a special study of these relations.

H. L. W.

8. *The Deviation of Rubidium Rays in Magnetic Fields*.—The question as to whether slow α -rays or β -rays accompany the disintegration of rubidium has been settled by an investigation of KARL BERGWITZ. The apparatus used consisted essentially of a rectangular zinc box which was screwed in place over the stem of a Wulf bifilar electrometer. This box was divided into two compartments by a partition made of the finest cigarette paper. The larger compartment was symmetrically placed with respect to the stem of the electrometer and it constituted the ionization chamber. The smaller room was eccentric, it had 20 grams of rubidium chloride on its floor, and it was situated between the poles of an electro-magnet.

In performing an experiment the normal loss of potential in nine hours was first observed with the rubidium salt in the adjacent chamber. Then the electro-magnet was excited and the decrease of potential in nine hours was again determined. Next the magnetic field was removed and the normal leak tested as in the first instance. Finally the magnetic field was excited in the reverse direction and the loss for nine hours was read. The initial potential difference was always chosen as 250 volts. In order to obtain information concerning the softness of the rays the series of measurements was repeated with different magnetic field strengths. The numerical data and curves show that the

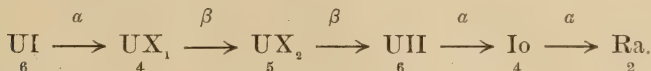
radiation from rubidium consists of β -rays. Further experimentation enabled the author to estimate the speed of these rays as 1.85×10^{10} cm/sec.—*Physik. Zeitschr.*, No. 14, July 1913, p. 655.

H. S. U.

9. *Researches in Magneto-Optics*; by P. ZEEMAN. Pp. xv, 219, with 74 figures and 8 plates. London, 1913 (Macmillan and Co.).—Since this volume is a member of the series entitled "*Macmillan's Science Monographs*" it is unique and authoritative, inasmuch as the author describes chiefly his own contributions to the subject with special reference to the magnetic resolution of spectrum lines. The material in the different chapters has been arranged in the main historically. The author's style is remarkably simple and lucid, the photographs reproduced in the plates are very clear, and the typographical work is a model of accuracy and neatness. The index is immediately preceded by two complete bibliographical lists of which the first refers to Zeeman's original papers only, while the second gives all the pertinent publications starting with the year 1896 and including 1912. Consequently this monograph is a very valuable contribution to the subject of magneto-optics.

H. S. U.

10. *A New Element, Uranium X₂*.—The following important conclusions have been drawn by K. FAJANS and O. GÖHRING from their latest investigations. (a) Uranium X is complex and consists of two elements symbolized by UX₁ and UX₂. The half-value period of 24.6 days, formally ascribed to uranium X, belongs to uranium X₁. (b) The half-value time for the new element, UX₂, is 1.15 minutes and its constant of disintegration equals 0.0100 sec^{-1} . (c) Uranium X₂ emits hard β -rays only and these are identical with the hard β -rays of uranium X. The soft β -rays of uranium X pertain to uranium X₁. The coefficients of absorption in aluminium are given as 500 cm^{-1} and 15 cm^{-1} for the soft and hard β -rays respectively. In the case of uranium X₁ hard β -rays could not be detected. These facts constitute a new verification of the rule that very hard and very soft β -rays are emitted by short- and long-lived elements, in the order named. (d) Uranium X₂ is electrochemically "nobler" than uranium X₁. (e) The chemical properties of uranium X₂ are in full accord with the assumption that it belongs in the fifth group of the tenth series of the periodic table and has tantalum as its closest analogue. (f) The beginning of the family tree of the uranium series should read:



—*Physik. Zeitschr.*, No. 18, Sept., 1913, p. 877. H. S. U.

11. *Mechanics and Heat*; by J. DUNCAN. Pp. xiii, 381, with 314 figures. London, 1913 (Macmillan and Co.).—This volume contains the subject-matter of an elementary course in *applied* physics, and is especially designed for use in the upper forms of certain secondary schools and for candidates preparing to take

the civil service examinations for second division clerkships. About the same amount of space is devoted to the subjects of mechanics and heat. Ample opportunity is afforded the student to apply the principles explained in the text by solving the problems (333) collected at the ends of the chapters and by performing the experiments (68) suggested. The various constituent parts of each half of the book form a very coherent whole, and the illustrations are apt and well-drawn. In particular, the sections dealing with steam and internal-combustion engines seem to be especially attractive. The text-proper is followed by tables of physical and mathematical constants, answers to the numerical exercises, and a subject index.

H. S. U.

12. *Practical Physics for Secondary Schools*; by N. HENRY BLACK and HARVEY N. DAVIS. Pp. ix, 487, with 465 figures and 17 plates. New York, 1913 (The Macmillan Co.).—One of the most important principles used consistently throughout this book is expressed by the following quotation: "We believe that it is most important for teachers to select carefully just what material they can best use, and to teach that *thoroughly*, rather than try to touch upon many topics superficially." The value of the text is enhanced by the summaries of principles which are given in full-faced type at the end of each chapter. The volume contains an unusually large number (769) of numerical problems and questions. The latter are especially well selected and are calculated to make the student observant and thoughtful. Two examples may not be superfluous: "Why is it that the United States and Great Britain are the only two civilized countries that do not use the metric system commercially?" and "Mark Twain in his 'Tramp Abroad' tells of stopping on his way up a mountain to 'boil his thermometer.' What did he do, and why?"

On the other hand, the manner of presentation of certain topics is open to serious question. The authors say: "Our treatment of acceleration, Newton's laws, kinetic energy and momentum, is essentially different from either the dyne and poundal method common in physics textbooks, or the "slug" or "wog" method of engineers, and is apparently new." Newton's second law is stated: "*The acceleration of a given body is proportional to the force causing it.*" This law is formulated as

$$\frac{F}{W} = \frac{a}{g}.$$

"It [the dyne] can be defined as 1/980 of a gram weight." Again:

"The expression $\frac{Wv}{g}$ is called the **momentum** of a moving body." Finally: "The resistance of a mil foot of wire is sometimes called the **specific resistance** of the substance. . . ."

H. S. U.

13. *Beyond the Atom*; by JOHN COX. Pp. 151; 11 figures and 1 plate. Cambridge, 1913 (University Press).—"This essay

is an attempt to tell in short compass the romantic story of the discoveries which within the last decade have led us beyond the atom." In other words, radio-active and allied phenomena are treated in the text from the historic, descriptive, and theoretical standpoints. In general, the author's style is very pleasing and his presentation of the subject is logical and sufficiently accurate. In some places, however, the process of deriving information from old editions of standard works has led to inconsistencies and inaccuracies of statement which would probably be misleading to the lay reader. Moreover, since the preface is dated "*February, 1913,*" it is fair to express disappointment at the omission of the recent discoveries by Friedrich, Knipping, Laue, Bragg, and others, of the effect of crystalline structure on Röntgen rays. The book closes with a short bibliography followed by a subject-index.

H. S. U.

14. *Physikalische Chemie der homogenen und heterogenen Gasreaktionen, unter besonderer Berücksichtigung der Strahlungs- und Quantenlehre sowie des Nernstschen Theorems*; von Dr. KARL JELLINEK. Pp. xiv, 844. Leipzig, 1913 (S. Hirzel).—The original plan of this ambitious work is undoubtedly very well stated in this title. The encyclopedic thoroughness with which it has been carried out would seem, however, to call for at least an inversion of the title. We have here in one volume a treatise in some detail on general thermodynamics; one in quite minute detail on the thermodynamics of gas reactions, leading up to Nernst's so-called "third law"; a very full sketch of the kinetic theory of matter, including both the older atomic and newer electronic hypotheses; and a comprehensive account of the theory of radiation and its culmination in the "quantum" hypothesis. Further, much space is devoted to the experimental methods used in testing the predictions of the various theories. Thus it is seen that the work can fairly be called compendious, and as a reference book it will be found useful by others than physical chemists, for whom presumably it was written. The very complete indices and bibliography add much to its value in this respect.

The main purpose of such a detailed development of these diverse doctrines of physics is to afford a basis for discussion of their inter-relations; in particular to show the significance which the "quantum" hypothesis and the electron theory of matter have for Nernst's "third law." In the main it may be said that the discussion is as adequate as it is timely. Of course, in a work of this magnitude it is not difficult to pick flaws, but the reviewer has detected none of a serious nature. The general criticism may be made that in the mass of detail through which the author leads us, one is apt to lose sight of the main relations which it is the prime object of the work to elucidate. In particular, the physicist or the mathematician may object to the unnecessary discursiveness of the mathematical portions—an objection, however, which may appear as an advantage to the less mathematically minded physical chemist.

In the development of the classical thermodynamics there are some apparent misstatements, notably the ascription of the Stirling cycle to Carnot. One omission of some importance in a work of such encyclopedic pretensions has been noted. In the discussion of the difficulty which arises in the electron theory of metals in the matter of specific heat, the fact that the number of free electrons demanded by the theory is vastly too great to be in accordance with the observed specific heats, is pointed out; but the alternative hypothesis of Sir J. J. Thomson, which does away with this difficulty, is apparently overlooked.

Nevertheless, as a whole (aside from the typographical errors which are too numerous) the book contains remarkably few slips, and can be recommended as a reference work of value in the very considerable fields which it aims to cover.

L. P. W.

II. GEOLOGY.

1. *Virginia Geological Survey*, T. L. WATSON, Director. Bulletin No. VII, *Geology of the Gold Belt in the James River Basin, Virginia*; by STEPHEN TABER, Assistant Geologist. Pp. xii, 271, 10 pls., 22 figs., map in pocket, 1913.—The Virginia Survey has planned a series of reports covering the gold-bearing rocks of the state, which will serve as detailed areal studies as well as contributions to economic geology. In the present bulletin the general geology and petrography of pre-Cambrian quartzites, schists and gneisses; Ordovician conglomerate, quartzite, schist and slate; Triassic sandstone and dikes, is discussed. The igneous rocks described include greenstone schists, quartz, feldspar porphyries, rhyolites, granites (with analysis), pegmatites, hornblende schists, diorite, diabase. The several periods of peneplanation are sketched in a chapter on Physiography, and a conclusion is reached that the Piedmont belt has remained above the sea since Ordovician time. Following a discussion of structure and metamorphism, the gold mines of the area, both vein (assigned to the Cambrian) and placer are treated in detail. Most of the mines have been abandoned. Following the discovery of gold in the James River valley in 1829 and the maximum output of \$104,000 in 1833, the production averaged \$56,000 yearly until the outbreak of the Civil War. Since that date the production in Virginia has averaged about \$6,000 yearly.

H. E. G.

2. *Sixteenth Annual Report of the Geological Commission, Cape of Good Hope, Department of Mines, 1911 (1912)*. Pp. v, 136, 2 maps and text figures.—The Annual Report for 1911 includes three papers: Report of the Geological Survey of Parts of the Divisions of Van Rhyne's Dorp and Namaqualand, by A. W. Rogers; Report on the Geological Survey of part of the Transkei, by A. L. duToit; Report on the Geological Survey of Part of the Stormbergen, by A. L. duToit.

A. W. Rogers, the Director of the Survey, has succeeded in determining the order of succession in the Nieuwerust, Malmesbury, and Ibiquas series, and correlating them with the Nama formation of German Southwest Africa. The existence of gneisses of both pre-Nama and post-Malmesbury ages has been established. Dr. Rogers does not accept the view of Hochstetter and others that the straightness of the west coast is due to faulting but believes rather that the intersection of the sea with a bent surface produced after peneplanation explains the linear quality. Detailed descriptions of the Nieuwerust Series, consisting of arkose, quartzite and shale; the Malmesbury Series, chiefly slates, and of the Ibiquas Series, conglomerates in part, are given. The area is intricately faulted and cut by quartz porphyry and monchiquite dikes. An interesting feature of the report is a discussion of sixteen nepheline-basalt pipes of a character new to science. Dr. duToit's work in the Transkei has brought to light an important monoclinical flexure dipping into the Indian ocean and has made possible the restoration of an ancient coastal plateau about fifty miles wide. The present coast line is shown to be sinking. A fortunate discovery of fossils places the Umgazana beds in the Upper Cretaceous and allows correlations heretofore impossible. Dr. duToit also describes a group of remarkable volcanic necks filled with light yellow tuft of the Drakensberg type. Like some other reports of the Cape of Good Hope Geological Commission, the present volume is decreased in value by lack of suitable maps and illustrations.

H. E. G.

3. *Sixth Annual Report (New Series) of the New Zealand Geological Survey, Session II, 1912.* Pp. 11; map bound with report.—The personnel of the New Zealand Survey is now as follows: Percy Gates Morgan, M.A., Director; John Henderson, M.A., D.Sc., Mining Geologist; James Allan Thomson, M.A., D.Sc., Paleontologist; John Arthur Bartrum, M.Sc., Assistant Geologist; George Edward Harris, Draughtsman; Henry Saxon Whitehorn, Assistant Topographer.

Field work for 1912 included surveys of the Bullor-Mokihinui and the Aroha subdivisions. The paleontologist with assistants is actively engaged in describing the fossils stored in the Museum; 120,000 specimens from 847 localities obtained by geologists of the old Survey, in addition to other collections, remain to be described. Dr. Thomson is confining his attention to Cretaceous and Tertiary material, and has placed the fossils from other strata in the hands of outside specialists.

H. E. G.

4. *Geological Survey of Western Australia, 1912.*—The following publications have been received:

(1) Bulletin No. 42, Contributions to the Study of the Geology and Ore Deposits of Kalgoorlie, East Coolgardie Goldfield. Part I, by E. S. SIMPSON and C. G. GIBSON. Pp. 198; 2 maps, 50 figs. Chapter I by Mr. Gibson includes an outline of the general geology and a detailed petrographic discussion of greenstones, quartz and feldspar porphyries and peridotites. The composition

and structure of the ores at Kalgoorlie and Boulder have been studied by Mr. Simpson. The report is illustrated by 40 microphotographs.

(2) Bulletin No. 43, Petrological Contributions to the Geology of Western Australia, by R. A. FARQUHARSON, Petrologist. Pp. 100, 16 figs. The first report issued by the recently appointed petrographer of the Western Australian Survey includes an elementary treatise on rocks and rock-making minerals, and petrographic descriptions with analyses of selected rocks from eight different areas.

(3) Geological Investigations in the country lying between Latitude 28° and $29^{\circ} 45'$ south, and Longitude $118^{\circ} 15'$ and $120^{\circ} 40'$ east, embracing parts of the North Coolgardie and East Murchison Goldfields, by H. W. B. TALBOT. Pp. 61, 11 figs., 1 geol. map. Beginning with the report of Mr. Talbot, the Survey plans to issue a series of bulletins dealing with the geology outside of those areas which, because of their commercial importance, have already been described. A reconnaissance geological map of large but little known territory is expected to be the result of this work. The nature of the country traversed by Mr. Talbot and Mr. Homan (topographer) may be judged from the fact that camels were used for riding and packing.

(4) Bulletin No. 46, A General Description of the northern portion of the Yilgarn Goldfield and the southern portion of the North Coolgardie Goldfield, by H. P. WOODWARD. Pp. 23, 2 maps. This report is designed particularly as a guide to prospectors and its chief value lies in the delineation of large sand-covered granite areas which possess no economic importance.

(5) Bulletin No. 47, The Mining Geology of the Kanowna Main Reef Line, Kanowna, Northeast Coolgardie Goldfield, by T. BLATCHFORD and J. T. JUTSON. With Petrological notes by R. A. FARQUHARSON, and Chemical Notes by E. S. SIMPSON. Pp. 106 ; 3 maps, 15 figs. The geology of the region including Kanowna has been discussed in several reports previously issued by the Western Australia Survey. The present bulletin covers the results of a special economic survey of the "Kanowna Main Reef" and contains much structural and petrographic detail.

(6) Bulletin No. 50, The Geology and Mineral Industry of Western Australia, by A. GIBB MAITLAND and A. MONTGOMERY. Pp. 68, 1 map, 7 figs. The summary of the geology of Western Australia will be found most helpful, especially to geologists who are unacquainted with the local features. Heretofore it has been well nigh impossible to gain from economic reports on widely separated areas a comprehensive view of the earth history of this part of the world. Following a short description of the Coastal Plain, the Hill Ranges, and the Interior Plateaus and Plains, the authors give a brief but clear account of the pre-Cambrian granites, gneisses and schists, containing laminated cherts and jaspers, which cover 975,920 square miles ; of the Cambrian identified by *Olenellus* and *Salterella* ; of the Nullagine series,

possibly also Cambrian; of the highly contorted quartzites, sandstones and shales assigned to the Silurian; of the fossiliferous Devonian; of the Permo-Carboniferous containing glaciated boulders and an extensive flora and fauna; of the richly fossiliferous Jurassic, and Cretaceous sediments; and of the Tertiary sediments which, in the Champion Bay district, rest unconformably on Jurassic strata. The occurrence and economic value of gold, copper, lead, tin, tantalum, iron, coal, salt, phosphates and water are discussed, and statistics of production, including the year 1911, are given.

H. E. G.

5. *Recurrent Tropicidoleptus zones of the Upper Devonian in New York*; by HENRY S. WILLIAMS. U. S. Geol. Surv., Prof. Paper 79. Pp. 103, 6 plates, 1913.—An interesting paper showing in much detail how the *Tropicidoleptus* faunule, a Hamilton holdover, reappears at least three times in the Upper Devonian of central New York. These reintroductions, the author states, "may have resulted (1) from the alternate closing and reopening of an actual passageway which alternately prevented and permitted the access of the fauna and of waters favorable to them, or (2) from changes that affected the direction, character, or volume of existing ocean currents."

These three New York recurrent *Tropicidoleptus* faunas are also found at very similar horizons in Maryland (Swartz, Bull. Geol. Soc. America, xx, pp. 679-686, 1910).

C. S.

6. *Grundzüge der geologischen Formations- und Gebirgskunde*; by A. TÖRNQUIST. Pp. 296, 127 text figures. Berlin, 1913.—This book, which is intended for students of natural history and geography and for mining engineers, presents along broad and general lines the stratigraphy and tectonics of Europe. The presentation is from the historical viewpoint, and main stress is laid upon the geotectonics. The stratigraphy is studied rather from the paleogeographic relations and biologic environment than from the paleontologic side.

The geologic time table accepted in the work is old-fashioned, for in it the Murchisonian Silurian and the still older Carbon are continued as formations or periods. The author also holds to the Laplacian theory of earth origin, and nothing is said of the planetesimal theory.

Of illustrations there are one hundred and twenty-seven, the most instructive being the many profiles bringing out the geologic structure of Europe. Of paleogeographic maps there are four (Upper Carboniferous, Triassic, Jurassic, and Gault).

C. S.

7. *Igneous Rocks*; by J. P. IDDINGS. Vol. II, 8°; pp. 685. New York, 1913 (Wiley & Sons).—The first part of this work, devoted to the general and theoretical side of petrology and to the classification of igneous rocks, was published by the author in 1907. The present and completing volume treats of the description of the rocks, and of their geographical distribution, the work being about equally divided between the two subjects.

The book opens with a discussion of the scope and method of description, in which, after the serial nature of the objects to be considered is brought out by the use of tables containing in graphic form the results of a vast mass of chemical data, the urgent need of quantitative methods in classification is demonstrated. The author then proposes a system in which the present ill-defined qualitative one, so generally used, is brought into more definite form by the injection into it of a certain amount of quantitative method, thus correlating it in broad features with the quantitative system, as already forecast in volume I, pp. 348-350. The rocks are thus divided into six divisions, as follows :

I,	characterized by quartz.
II	“ “ quartz and feldspar.
III	“ “ feldspar.
IV	“ “ feldspar and feldspathoids.
V	“ “ feldspathoids.
VI	“ “ mafic minerals.

The feldspathic rocks are again divided according to the alkalic or alkalicalcic nature of the feldspars, and further divisioning according to the relative proportions of feldspathic (or feldspathoidic) and of mafic minerals is provided. The term mafic, it may be added, is a shorter equivalent for ferromagnesian.

On this basis the rocks have been briefly treated, the object being to present their mineralogic and chemical characteristics, and to bring into correlation the variously named types described by petrographers rather than to furnish an encyclopedia of petrographical data. We believe the author has done well in thus restraining himself, for information of this nature is already available in the voluminous treatises of Rosenbusch and Zirkel. On the chemical side, however, the material is abundant and this emphasis of the chemical characteristics of igneous rocks is one of the chief and most valuable features of the book. It is shown in the presence of 71 tables, each containing from one to two dozen well-selected analyses, with their calculated norms. The aphanitic rocks are treated in close connection with their chemically equivalent phanerites, thus showing the varied forms of crystallization of chemically similar magmas.

The second portion of the work devoted to the occurrence of igneous rocks furnishes the most comprehensive treatment of the problem of petrographical provinces which has been attempted. After a general discussion each great division of the earth is considered in detail and the occurrence of its igneous rocks is shown upon a colored map, which facilitates the perception of their separation into different provinces. In Europe, for example, they are considered after the following grouping :

- 1 Scandinavia and Finland.
- 2 Ural Mountains.
- 3 British Isles.
- 4 France, Spain, Portugal.

- 5 Switzerland, Germany, Austro-Hungary, and southern Russia.
- 6 Italy and West Mediterranean islands.
- 7 Balkan Plateau, Greece, Aegean isles.
- 8 Asia Minor, Persia, Arabia.

The last grouping is taken as a matter of convenience.

In each group the chief occurrences of the rocks are briefly described, with remarks directing attention to their salient features, while frequent tables of analyses add greatly to the value of the presentation. The labor of digesting the colossal mass of literature necessary for this work must have been immense, and some idea of it may be gained from the comprehensive bibliography submitted in the final pages. This geographical conspectus is a lasting benefit to working petrographers in enabling them to easily compare material with that already described in the chief publications upon all parts of the world. In addition the general résumés of the different provinces will be of value in directing attention to their chief peculiarities. The wide travels of Professor Iddings and his personal acquaintance with the rocks of many regions give an additional authority to this portion of the work.

On the whole it may be said that the completion of this great work marks a distinct step forward in the science of petrology, in that it is the most comprehensive and fundamental treatment of the subject which has yet appeared, in which also the bearing of the most recent advances in related sciences have been considered. The amended qualitative classification proposed seems the most reasonable way out of this vexed problem, in combining our heritage from the past with the greater precision demanded from present-day workers in science and in indicating the path along which improvement may be made in the future. It is perhaps needless to say that the volume is a necessity for every worker in the science. It is well and attractively printed and both author and publisher are to be congratulated on its appearance.

L. V. P.

8. *Introduction to the Study of Igneous Rocks*; by GEO. I. FINLAY. 12°, pp. 228, 59 figs., 3 col. pls. New York, 1913 (McGraw-Hill Co.).—The object of this little work is clearly indicated in the title. The author first discusses the classification of rocks from the generally used qualitative method and then takes up their determination in hand specimens. This is followed by a brief discussion of the movement of light in crystals and the identification of the essential rock minerals in sections by optical methods. A brief description of the accessory minerals is given and the most important varieties of the igneous rocks are then presented. Less important types are mentioned in tabular form. After giving the proper method for describing rocks the work closes with a rather full account of the Quantitative System of Classification. Examples for the calculation of the norm are discussed and the necessary numerical tables are

appended. The colored chart of Michel-Lévy for maximum birefringences and the table of the chief characters of the rock minerals will be found useful in identification.

On the whole the author has done his work well, the chief fault being that which is necessarily inherent in books of this class, where the attempt is made to compress into so small a compass any comprehensive account of such a great mass of material as the subject of petrology affords. It should not be understood, however, that, as is so often the case, the book is a mere synopsis. The author has wisely restricted himself to a relatively few important matters and has treated these with a fair degree of fullness. It is only in the description of the rocks that the synoptic character becomes evident and it would seem as if this part of the work might have been somewhat more expanded, with advantage to the student.

For those who desire to obtain a general notion of the science of petrology, to familiarize themselves with the method of determining the common igneous rocks by the use of the microscope and, provided a chemical analysis of a rock has been made, to properly calculate its position in the quantitative system, this little book, which occupies a distinct place of its own, will be found very useful. It is well printed and conveniently bound.

L. V. P.

9. *Der Vulkanismus*; von F. VON WOLFF. 2 vols.; vol. 1, first half. 8°, pp. 300, 80 figs. Stuttgart, 1913 (F. Enke).—This is intended as a rather comprehensive work on the igneous activities of the earth. This may be seen from the subjects of various chapters; thus chapter two treats of the theater of volcanic activity and the physical conditions ruling there, chapter three gives a full discussion of the properties of the magma, of the process of crystallization, structure of the rocks, gaseous components, etc. Then follows the treatment of the magmatic zone, in which the geographic distribution of igneous rocks, differentiation, assimilation, and kindred subjects are considered. Next the geologic mode of occurrence of intrusive rocks and the mechanics of intrusion are dealt with in detail. Post volcanic processes connected with intrusions, that is to say contact metamorphism, follow, and the present portion ends with an account of submarine eruptions.

The literature of the various subjects is quite fully considered, the author giving short, clear statements of the views of other writers, accompanied by critical comments of his own. He has introduced considerable original matter, and this and the clear method of presentation, as well as the references to the work of others, make the book not only interesting but very useful for investigators and teachers in this field of geology. It is well and clearly printed, but some of the figures, introduced from the older works, are for a modern one rather crude. While the work is to be distinctly commended, and there is no opportunity here for a critical review of the subject-matter, one detail may be considered. In treating of the geographical distribution of igneous

rocks, the author adopts the terms proposed by Becke of "Atlantic" and "Pacific" families, for alkalic and sub-alkalic. After making a rather rapid but comprehensive survey of the known occurrences of igneous rocks in the Pacific, he says: "The result of this investigation can be shortly comprised in the statement that the Pacific Ocean, with the exception of its andesitic borders (Umrahmung) is an Atlantic magmatic province." Further comment on the use of these terms seems unnecessary.

L. V. P.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Publications of the Carnegie Institution of Washington.*—Recent publications of the Carnegie Institution are noted in the following list (continued from vol. xxxv, p. 466):

No. 54. Research in China. In three volumes and atlas. Volume III. The Cambrian Faunas of China; by CHARLES D. WALCOTT. A report on Ordovician Fossils collected in Eastern Asia in 1903-04; by STUART WELLER. A report on Upper Paleozoic Fossils collected in China in 1903-04; by GEORGE H. Girty. Pp. vi, 375; 24 pls., 9 figs.

No. 74, Vol. VII. The Vulgate Version of the Arthurian Romances, edited from Manuscripts in the British Museum; by H. OSKAR SOMMER. Supplement: Le Livre D'Artus, with glossary. Pp. 370.

No. 167. The Infinitive in Anglo-Saxon; by MORGAN CALLAWAY, JR. Pp. xiii, 339, with 4 Appendixes.

No. 168. Measures of Proper Motion Stars made with the 40-Inch Refractor of the Yerkes Observatory in the years 1907 to 1912; by S. W. BURNHAM. Pp. iv, 311.

No. 173. The Differentiation and Specificity of Starches in relation to genera, species, etc. Stereochemistry applied to Protoplasmic Processes and Products, and as a strictly scientific basis for the Classification of Plants and Animals; by EDWARD T. REICHERT. Part I. Pp. xvii, 342; 102 pls. Part II. Pp. xvi, 343-900; 450 charts.

No. 177. The Venom of Heloderma; by LEO LOEB, with collaborators. Pp. vi, 244; 38 figs.

No. 178. Botanical Features of the Algerian Sahara; by WILLIAM A. CANNON. Pp. vi, 81; 36 pls., 84 figs.

No. 179. Reversion in Guinea-pigs and its explanation; by W. E. CASTLE. Pp. 10; 4 tables. Experimental Studies of the Inheritance of Color in Mice; by C. C. LITTLE. Pp. 11-102; 5 plates. (Papers Nos. 18, 19 of the Station for Experimental Evolution at Cold Spring Harbor, New York.)

No. 180. The Freezing-Point Lowering, Conductivity, and Viscosity of Solutions of certain Electrolytes in Water, Methyl Alcohol, Ethyl Alcohol, Acetone, and Glycerol, and in mixtures of these solvents with one another; by HARRY C. JONES and collaborators. Pp. vii, 214; 85 figs.

No. 181. Permo-Carboniferous Vertebrates from New Mexico; by E. C. CASE, S. W. WILLISTON, and M. G. MEHL. Pp. iii, 81

No. 186. The Diffusion of Gases through Liquids and allied experiments ; by CARL BARUS. Pp. iv, 88 ; 38 figs.

No. 190. The Absorption Spectra of Solutions affected by Temperature and by Dilution : A quantitative study of Absorption Spectra by means of the Radiometer ; by HARRY C. JONES and J. SAM GUY. Pp. vii, 93 ; 22 pls., 43 figs.

Also (Oct. 8) : Classified Descriptive List of Publications with prices and authors index.

2. *The Mining World Index of Current Literature*. Vol. III, first half year, 1913. By GEORGE E. LISLEY. Pp. xxvi, 158. Chicago, 1913 (Mining World Company) —The second volume of this index was noticed in the July number (p. 90). The volume now issued covers Jan.-June, 1913, and is planned to embrace the world's literature in mining, metallurgy, and kindred industries for this period. References are classified according to subject, and an authors index closes the volume. The value of this index to all concerned with the subjects covered is at once obvious.

OBITUARY.

DR. CHARLES GREENE ROCKWOOD, from 1877 to 1905 professor of mathematics at Princeton University, died on July 2 in his seventy-first year.

PROFESSOR JOHN ROBIE EASTMAN, the astronomer, died on September 26, at the age of seventy seven years. He was an assistant at the U. S. Naval Observatory from 1861 to 1865, and professor of mathematics, U. S. N., from 1869 to 1898.

DR. ALEXANDER MACFARLANE, the mathematician, at one time professor of physics in the University of Texas and later residing in Canada, died in September last in his sixty-third year..

PROFESSOR JOHN MILNE, the eminent English seismologist, died on July 31 at the age of sixty-three years.

SIR WALTER NOEL HARTLEY, formerly professor of chemistry at the Royal College of Science in Dublin, died on Sept. 11 in the sixty-eighth year of his age.

PROFESSOR HUGH MARSHALL, the Scotch chemist and crystallographer, died on September 5 at the age of forty-five years.

DR. PHILIP LUTLEY SOLATER, the veteran zoologist, died on June 27 at the age of eighty-four years.

DR. HERMANN CREDNER, emeritus professor of geology at the University of Leipzig, and former director of the Royal Geological Survey of Saxony, died on July 22d, at the age of seventy-two. His "Elemente der Geologie" has gone through eleven editions (1872-1912). When a young man, Credner lived for some years in America, and published papers on the geology of New York and New Brunswick (1865), Virginia (1866), Georgia (1867), Lake Superior and Michigan (1869), and the Cretaceous of New Jersey (1870).

DR. HUGO LASPEYRES, professor of mineralogy at the University of Bonn, died on July 22.

DR. HEINRICH WEBER, professor of mathematics in the University of Strassburg, died on May 17 at the age of seventy-one years.

WARD'S NATURAL SCIENCE ESTABLISHMENT

A Supply-House for Scientific Material.

Founded 1862.

Incorporated 1890.

DEPARTMENTS:

Geology, including Phenomenal and Physiographic.

Mineralogy, including also Rocks, Meteorites, etc.

Palaeontology. *Archaeology* and *Ethnology*.

Invertebrates, including Biology, Conchology, etc.

Zoology, including Osteology and Taxidermy.

Human Anatomy, including Craniology, Odontology, etc.

Models, Plaster Casts and Wall-Charts in all departments.

Circulars in any department free on request; address

Ward's Natural Science Establishment,

76-104 College Ave., Rochester, New York, U. S. A.

EIMER & AMEND

Complete Laboratory Furnishers

Chemical Apparatus, Balances, etc.

C. P. and T. P. Chemicals and Reagents

Platinum Ware, Best Hammered Blowpipe Outfits
and Assay Goods

**WE CARRY A LARGE STOCK OF
MINERALS FOR BLOWPIPE WORK,
ETC.**

EST'D - 1851
203 - 211 - THIRD - AVE
NEW-YORK-CITY

CONTENTS.

	Page
ART. XL.—Upper Devonian Delta of the Appalachian Geosyncline ; by J. BARRELL	429
XLI.—Optical Bench for Elementary Work ; by H. W. FARWELL	473
XLII.—Volcanic Research at Kilauea in the Summer of 1911 ; by F. A. PERRET ; with Report by A. BRUN	475
XLIII.—Observations on the Stem Structure of Psaronius Brasiliensis ; by O. A. DERBY	489
XLIV.—Fauna of the Florissant (Colorado) Shales ; by T. D. A. COCKERELL	498
XLV.—The Photoelectric Effect ; by L. PAGE	501
XLVI.—Graphical Methods in Microscopical Petrography ; by F. E. WRIGHT. (With Plates II to IX)	509
XLVII.—A Graphical Plot for Use in the Microscopical Determination of the Plagioclase Feldspars ; by F. E. WRIGHT. (With Plate X)	540
XLVIII.—On the Influence of Alcohol and of Cane Sugar upon the Rate of Solution of Cadmium in Dissolved Iodine ; by R. G. VAN NAME and D. U. HILL	543
XLIX.—Comparative Studies of Magnetic Phenomena. IV. Twist in Steel and Nickel Rods due to a Longitudinal Magnetic Field ; by S. R. WILLIAMS	555

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Hydrides of Boron, A. STOCK : Metallic Beryllium, FICHTER and JABLONZYNSKI, 562.—General Chemistry, Theoretical and Applied, J. C. BLAKE : A Dictionary of Applied Chemistry : General and Industrial Organic Chemistry, 563.—Chemistry and its Relations to Daily Life : Studies in Valency : Deviation of Rubidium Rays in Magnetic Fields, K. BERGWITZ, 564.—Researches in Magneto-Optics, P. ZEEMAN : A New Element, Uranium X : Mechanics and Heat, 565.—Practical Physics for Secondary Schools : Beyond the Atom, 566.—Physikalische Chemie der homogen und heterogenen Gasreaktionen, 567.

Geology—Virginia Geological Survey : Sixteenth Annual Report of the Geological Commission, Cape of Good Hope, Department of Mines, 1911 (1912), 568.—Sixth Annual Report (New Series) of the New Zealand Geological Survey, Session II, 1912 : Geological Survey of Western Australia, 1912, 569.—Recurrent Tropidoleptus zones of the Upper Devonian in New York : Grundzüge der geologischen Formations- und Gebirgskunde : Igneous Rocks, J. P. IDDINGS, 571.—Introduction to the Study of Igneous Rocks, G. I. FINLAY, 573.—Der Vulkanismus, 574.

Miscellaneous Scientific Intelligence—Publications of the Carnegie Institution of Washington, 575.—The Mining World Index of Current Literature, 576.

Obituary—C. G. ROCKWOOD : J. R. EASTMAN : A. MACFARLANE : J. MILNE : W. N. HARTLEY : H. MARSHALL : P. L. SCLATER : H. CREDNER : H. LASPEYRES : H. WEBER.

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEORGE L. GOODALE, JOHN TROWBRIDGE,
W. G. FARLOW AND WM. M. DAVIS, OF CAMBRIDGE,

PROFESSORS ADDISON E. VERRILL, HORACE L. WELLS,
LOUIS V. PIRSSON, HERBERT E. GREGORY
AND HORACE S. UHLER, OF NEW HAVEN,

PROFESSOR HENRY S. WILLIAMS, OF ITHACA,
PROFESSOR JOSEPH S. AMES, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES

VOL. XXXVI—[WHOLE NUMBER, CLXXXVI].

No. 216—DECEMBER, 1913.

NEW HAVEN, CONNECTICUT

1913.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. \$6.40 to countries in the Postal Union; \$6.25 to Canada. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).

HODGKINSONITE, A NEW MINERAL.

We have been fortunate enough to secure the best specimens of this very rare mineral. It is from the celebrated Franklin Furnace mines and is a rare compound, the formula of which is $Mn(ZnOH)_2SiO_4$. It crystallizes under the monoclinic system and is pink in color associated with barite. In a few specimens it is associated with the rare minerals Pyrochroite and Gageite. The whole makes a very pretty specimen. Prof. Charles Palache has analyzed and will soon publish a description of it. The quantity found is scarcely enough to supply the scientific institutions who will want a specimen. Prices range from \$1.00 to \$25.00.

A NEW OCCURRENCE—Fluorescent Willemite with Rhodocrosite.

The Willemite occurs in transparent crystals running in size from 2 millimeters in diameter to almost a hair in thickness. They occur in cavities on Rhodocrosite, making a very beautiful specimen. Under a current they show a strong fluorescence. Prices range from \$1.00 to \$5.00.

SYNTHETIC GEMS.

It is remarkable the interest that has been taken by scientists in these wonderful scientific discoveries. The Corundums are now produced in Pigeon blood, Blue, Yellow, Pink and White. Also the new Indestructible Pearls in strings with gold clasps. These are identical in hardness and rival in color and lustre the real gems. They can be dropped and stepped on without injury and are not affected by acids. My collection of the above is unrivalled, and prices of the same are remarkably low.

OTHER INTERESTING DISCOVERIES AND NEW FINDS

Will be found in our new Catalogues. These consist of a Mineral Catalogue of 28 pages; a Catalogue of California Minerals with fine Colored Plates; a Gem Catalogue of 12 pages, with illustrations, and other pamphlets and lists. These will be sent free of charge on application.

Do not delay in sending for these catalogues, which will enable you to secure minerals, gems, etc., at prices about one-half what they can be secured for elsewhere.

REMOVAL NOTICE.

Finding that at our recent location we were placed at a disadvantage in receiving and shipping our numerous consignments, we decided to return to our old location, where we are surrounded by the greatest gem and financial district in the world, and are near the vast shipping interests, Custom House, etc., etc. Our old offices have been entirely renovated in a beautiful manner, new cases have been fitted and all who take the trouble to call on us will find themselves well repaid by the beautiful display of minerals, gems, curios, etc., etc.

ALBERT H. PETEREIT

81-83 Fulton St.,

New York City.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. L.—*Some Lavas of Monte Arci, Sardinia*; by HENRY
S. WASHINGTON.

Introduction.—It is not generally known that near Monte Ferru, the well-known volcano of Sardinia, there is another, Monte Arci, not far distant, of only slightly smaller size, and yielding somewhat similar rocks. During a visit to Sardinia, undertaken in 1905 for the Carnegie Institution of Washington, two days were spent in examining part of the western flank of this volcano. As only a very small part of the volcanic mass was studied, the present paper is to be regarded as a preliminary one based on a hasty reconnaissance, and it is hoped to complete the study by a visit in the near future.* All the analyses in this paper were made by me, with the exception of a few quoted ones.

Our present knowledge of Monte Arci is due wholly to Count Alberto della Marmora,† the pioneer explorer and investigator of the island, whose many years of indefatigable labor have served as the foundation for most of our knowledge of its geology. So far as I know, there is no other description of the volcano, and it is not even mentioned in Cossu's‡ monograph on the island or in Tennant's§ book. The area of Monte Arci is embraced in Folio 217, I, II, III of the maps of the Istituto Geografico Militare (scale = 1 : 50,000).

TOPOGRAPHY AND GEOLOGY.

Monte Arci is situated about 20 km. southeast of the town of Oristano, near the center of the west coast of Sardinia and some

* My thanks are due Mr. C. W. Wright of Ingurtosu, Sardinia, for collecting additional specimens of rhyolite at Capanna.

† A. della Marmora, *Voyage en Sardaigne*, Part 3, *Geologie*, Vol. I, Turin, 1857.

‡ A. Cossu, *L'Isola di Sardegna*, Rome, 1900.

§ R. Tennant, *Sardinia and its Resources*, London, 1885.

15 kilometers from the sea. The railroad from Cagliari to Macomer skirts its western edge. It stands near the northwest end of the broad belt of Miocene limestone, known as the Campidano, which extends from Cagliari to Oristano. Its lavas overlies this, and beyond it are found the Quaternary deposits of the Gulf of Oristano. Like Monte Ferru* it probably began in late or post-Miocene time, but I obtained no data to decide its exact age. Della Marmora mentions Tertiary deposits intercalated with the Arci lavas in several places.

As the flows of Arci and Ferru do not meet, and the stratigraphy is as yet imperfectly known, it is impossible to decide now as to the relative age of the two volcanoes, or whether they were active simultaneously. Judging from the much greater erosion undergone by Arci, it would seem to be probable that this is the earlier of the two, at least as regards the time of extinction. The apparent shifting of the post-Miocene volcanic activity toward the north, as shown by the small recent cones of the Logoduro, favors this hypothesis.

The volcanic cone has been so deeply eroded as to have lost nearly all trace of its original outlines. The highest point is reached in the twin peaks of Trebina Longa (812 m.) and Trebina Lada (795 m.), which form a conspicuous landmark. These are situated on the west edge of a sort of platform, with a general elevation of about 700 meters and extending some 5 kilometers from north to south. From this ridge steep and narrow valleys radiate irregularly in every direction. Della Marmora considers this ridge to be part of the original crater wall, but, as I could only see it from a considerable distance, I must reserve my opinion as to the existence of remains of a crater. The western part may be visited from the stations of Uras and Marrubiu, while the small town of Ales serves as a base for study of the eastern portion.

It is not yet possible to give more than a very rough estimate of the area covered by the lavas, but judging from the descriptions and statements of della Marmora this may be placed provisionally at some 500 square kilometers, that of Monte Ferru being at least 700.†

PETROGRAPHY.

Della Marmora pointed out that Monte Arci, like Monte Ferru, consists of a core of feldspathic lavas, called by him trachytes and phonolites, covered by a later mantle of basaltic flows, which extend for many miles in all directions beyond the limits of the earlier lavas. My observations fully bear out his statement of the general structure of Arci, just as those of

* Cf. A. Dannenberg, *Sb. Preuss. Akad. Wiss.*, p. 856, 1903.

† A. Dannenberg, *Neues Jahrb., Beil. Bd.*, xxi, p. 7, 1905.

Doelter, Dannenberg, Deprat, and myself confirm his views as to the broad features of Ferru.

The specimens collected by me are of the following rocks :

Rhyolite,	liparose, (I.4.1.3)
Trachyte,	phlegrose, (I.5.1.3)
Andesite,	{ dacose, (II.4.2.4)
	{ tonalose, (II.4.3.4)
Basalt,	andose, (II.5.3.4)

Della Marmora mentions phonolites, apparently like those of Ferru, as being rather common, but I could find no occurrence of such rocks. They would seem, however, to occur most frequently in the eastern part of the volcano, which I did not visit. As, however, della Marmora's petrography was that of the first half of the nineteenth century, it is possible that his "phonolites" would not be called so now. His "trachytes" are in reality rhyolites.

Rhyolite (Liparose, I.4.1.3)

Rhyolites of various types are the most abundant rocks in the portions of the volcano visited by me. Their massive flows form the bulk of the spurs along the southwest edge of the mass and are well exposed in the narrow valleys (so-called *concas*) which cut into it. Judging from the descriptions of della Marmora* these rhyolites unquestionably constitute in great part the internal domal core of the volcano, reaching up to the basalt-crowned summits of the Trebinas.

Lithoidal Rhyolite.—What may be regarded as the typical rhyolite (the *trachyte ancienne* of della Marmora) is dense and lithoidal, of a dull luster and even fracture. It is very light in color, usually an ash-gray, but sometimes pinkish or bluish or even white. It is often somewhat banded with narrow streaks of lighter color which show well-marked flow structure. The flows are generally very massive and compact, but in the Canale Perdiera, north of Uras, the rhyolite is platy, splitting readily into thin (horizontal) slabs, which may be not more than a centimeter or so thick. Rhyolitic tuffs seem to be very rare.

The type is practically aphyric, the only phenocrysts visible being very rare and small crystals of feldspar and quartz, with an occasional small biotite table. Some specimens also show some small specks of a rose-colored mineral, none of which could be identified in the thin sections.

At a spring called Capanna, about 5 kilometers eastnortheast of Marrubiu, narrow crevices and lithophyal cavities of the rhyolite are drusy with very small quartz crystals. On these

* Op. cit., pp. 499-501.

druses are implanted small crystals of an unknown mineral. The crystals are about one- or two-tenths, and never over one-half of a millimeter in diameter. They consist of a hexagonal prism and the basal plane, with no traces of pyramids, are about equidimensional, and are frequently grouped in parallel position, much after the habit of some vanadinite. They are usually honey-yellow, but sometimes brownish, and in one specimen collected by Mr. Wright are a deep brick-red. Those collected would appear not to be fresh, as they are nearly all but hollow shells and are very friable. The mineral is a silicate, with alumina and a little iron (apparently as an impurity). It seems to contain no lime and gave no microchemical reaction for zirconia, so that it cannot be eudialyte, which is suggested by the hexagonal form and the color. The crystal form, as well as the absence of lime, also precludes withamite or thulite, and the occurrence on quartz in a highly silicic rhyolite make it seemingly impossible for the mineral to be nephelite, which these crystals much resemble, except for the color. The mineral is apparently the same as that which is seen megascopically as the pink specks mentioned above. The amount available (owing to the unfortunate breaking of the handle of my large hammer) is far too small for analysis, apart from the apparently decomposed condition of the material, so that identification and further investigation must await future more extensive collection at the locality.* What is apparently the same mineral occurs sparingly in the platy rhyolite of Canale Perdiera.

In thin section this type of rhyolite shows very rare and small phenocrysts of alkali feldspar, either in simple crystals or as Carlsbad twins, and thin plates of biotite, which is generally darkened and somewhat altered. The groundmass is of a common type, generally holocrystalline, though some glass may be present, and composed of very small, equant, subhedral alkali feldspars in a base of quartz and feldspar. In specimens from Canale Perdiera, Conca Cannas, Capanna and Conca su Ollastru there are small rounded spherulites of radiating feldspar crystals, while micropoikilitic patches of quartz and feldspar are often met with. Some specimens carry in the base a sort of felt of extremely minute needles, apparently of a pyroxene.

The chemical composition will be discussed later.

Perlite.—Highly vitreous rhyolites—both obsidians and perlites—are also common, though their mass is not as great as that of the lithoidal type. The perlites usually form flows intercalated with those of lithoidal rhyolite, as in the Canale Perdiera, above Conca su Ollastru, and Conca Connas. A per-

*The mineral was shown to the late Professor Penfield, who could suggest no probable identification.

lite also occurs as a well-defined dike some 20 to 30 meters wide and running vertically east and west, which cuts the platy rhyolite of Punta Brenta, near the entrance to Canale Perdiera. The rhyolite bordering it has been rendered much denser, of a brownish color, and with the platy structure well brought out, the plates being very thin and separated from each other by slightly vesicular material. In thin section the change is slight.

These perlites are all pure ash-gray in color, varying from rather dark to rather light, and show a distinct rather coarse to quite fine granular texture. The perlite which forms the dike at Punta Brenta and that from Conca Cannas show some small phenocrysts of feldspar and biotite, which are wanting in most of the specimens. A perlite from the ridge southeast of Capanna is rather platy and is thickly sprinkled with small (2–10^{mm}) rounded and subangular pieces of black obsidian. These have caused perlitic cracking around them, as they are surrounded by a shell of gray perlite.

In thin section the perlites show a clear, colorless glass, which is perlitically cracked, the amount of cracking and the size and perfection of the curves corresponding to the megascopic granularity. There are a few small phenocrysts of alkali feldspar and some thin tables of biotite, but the amount of these cannot be more than about one per cent, and in some specimens they are wholly wanting. The glass is sprinkled with microlitic crystals of alkali feldspar, very thin flakes of biotite and minute prisms of colorless pyroxene, all of which are arranged in a well-developed flow structure. Some of the specimens, notably those from the Conca su Ollastru, contain many streaks of brownish spherulites, which have developed around phenocrysts of feldspar or mica. These spherulitic growths are either spherical, axiolic, or more often reniform. A central core is rather dark brown, surrounded by a wide border of lighter color. These spherulites have no appreciable action on polarized light, and the perlitic cracks pass through them without change. A chemical analysis will be given later.

Obsidian.—Black obsidian was found in nearly all the conchas and, according to the descriptions of della Marmora, it is very common all over Monte Arci. It is generally scattered in angular fragments over or through the ground, in places so abundantly as to suggest the debris of a great factory of black bottles, to use della Marmora's simile. I observed it in place nowhere, and della Marmora notes it either as dikes or beds between rhyolite flows only in a few places.

These obsidians are extremely dense and compact, with highly perfect conchoidal fracture. They are jet black, show-

ing gray on thin edges, due to many black specks, and are absolutely free from phenocrysts of any kind. East of the Conca su Ollastru, in the Rione Prasuedu, were many angular, but somewhat worn, small fragments of a reddish brown obsidian mottled and streaked with black.

In thin section these black obsidians show an absolutely colorless glass, perfectly free from perlitic cracks. There are very few small crystals of feldspar and biotite, and many black opaque microlites, which are either short belonites or small trichitic bunches, the much curved hairs radiating from a common center. The red portions of the mottled obsidian pebbles show many thin, isotropic, bright orange or yellow streaks in a colorless glass.

Chemical Composition.—Three analyses made by me are given in the annexed table, one of the typical lithoidal rhyolite whose crevices contain the unknown hexagonal mineral, one of the perlite of the dike at Punta Brenta, and one of a typical obsidian.

Analyses of Sardinian Rhyolites.

	A	B	C	D	E	F	Aa	Ba	Ca
SiO ₂	73.09	70.50	74.61	74.76	73.23	72.05	1.218	1.175	1.244
Al ₂ O ₃	13.80	14.28	12.68	11.60	12.25	13.07	.135	.140	.124
Fe ₂ O ₃	1.28	0.75	0.09	3.50	3.25	2.93	.008	.005	.001
FeO	0.68	1.22	1.36	0.19	0.28	0.39	.010	.017	.019
MgO	0.37	0.49	0.21	0.18	0.13	0.66	.009	.012	.005
CaO	0.69	1.00	0.69	0.07	0.25	1.30	.013	.018	.013
Na ₂ O	3.77	3.62	3.68	4.35	4.44	3.49	.061	.058	.060
K ₂ O	5.36	5.28	4.77	4.92	4.32	4.55	.057	.056	.051
H ₂ O+	0.60	2.86	1.37			0.59			
H ₂ O—	0.72	0.10	0.04	0.64	1.74	0.24			
TiO ₂	0.38	0.47	0.08	tr.	---	0.40	.005	.006	.001
ZrO ₂	0.02	---	---	---	---	0.05			
P ₂ O ₅	0.07	0.11	n. d.	tr.	---	0.22	.001	.001	---
SO ₃	none	---	---	---	---	0.18			
MnO	tr.	0.04	n. d.	n. d.	---	0.04			
BaO	none	---	---	---	---	0.06			
	100.83	100.72	99.58	100.21	99.89	100.22			

A. Liparite. Capanna, near Marrubiu, Monte Arci.

B. Perlite. Punta Brenta near Uras, Monte Arci.

C. Obsidian. Conca Cannas, near Uras, Monte Arci.

D. Comendite. Comende, San Pietro Island. Dittrich, analyst. H. Rosenbusch, Elemente, 1898, p. 257.

E. Comendite. San Pietro Island. A. Johnsen, analyst. A. Johnsen, Neues Jahrb. Centralbl., 1912, p. 738.

F. Rhyolite. Macomer.

Aa, Ba, Ca, mol numbers of A, B, C.

The analyses are those of ordinary sodipotassic rhyolites and are much alike, the lower silica of the perlite (B) being due in part to the presence of water. The relations of the iron oxides in the holocrystalline rhyolite and the glassy forms are worth

noting, ferric oxide predominating in the first and ferrous oxide in the others.

They are much like the analyses of typical comendite (D, E), though this is slightly lower in alumina and higher in ferric oxide, in these respects resembling the pantellerites. The last are, however, notably more sodic.* An as yet unpublished analysis (F) of a red rhyolite which forms one of the pre-Tertiary sheets near Macomer is also given. This is like the others, but is somewhat higher in iron and lime.

The norms of the Monte Arci rhyolites are as follows:

	A	B	C
Q	28.50	26.58	31.80
Or	31.69	31.14	28.36
Ab	31.96	30.39	31.44
An	3.61	4.17	3.61
C	0.41	1.12	---
Hy	0.90	1.99	2.74
Il	0.76	0.91	0.15
Hm	0.48	---	---
Ap	0.34	0.34	---

From these it is seen that all these rhyolites fall in liparose (I.4.1.3), the liparite centrally and the perlite and obsidian distally,† being transitional toward (almost on the border of) the domalkalic rang, with the full symbol I.4.1(2).3. The small amount of normative corundum in A and B belongs, of course, to the biotite, and it may be worth noting that its amount is roughly proportional to that of the biotite seen in the specimens. The amounts of mafic minerals in the lithoidal rhyolite are so negligible that the mode is almost absolutely normative.

Trachyte (Phlegrose I.5.1.3).

The only occurrence of trachyte was found as blocks in the Conca Cannas, which are apparently derived from a flow in its south wall. This was not found, but it overlies rhyolite, of which the lower parts are composed.

The rock is rather light gray, very compact, and dopatie. Numerous equant to thick tabular crystals of glassy alkali feldspar are the only phenocrysts. They vary in size from 2 to 5^{mm}. The groundmass is gray, dense, felsitic and aphanitic.

In thin section the feldspar phenocrysts are seen to be of soda-microcline, either in simple crystals or Carlsbad twins. The extinction on *c*(001) is about 7°. They are quite free

*For recent analyses of these see H. S. Washington, Jour. Geol., xxi, 1913.

†This term "distal" is borrowed from the organic sciences to indicate either the intermediate or transitional position, near the border, in opposition to "central." The terms would seem to be self-explanatory.

from inclusions. Very small augite and magnetite anhedralons are also present, but are rare. The groundmass is dense and apparently holocrystalline. It consists of a cryptocrystalline aggregate of feldspar and quartz, showing no micropertthitic patches. There are many minute ragged anhedralons of augite and magnetite, and irregular grains of a brownish yellow, biaxial mineral, which may be a peculiar, or possibly slightly altered, pyroxene. A similar mineral is found in the sheet trachyte of Monte Muradu near Macomer.

Analyses of Sardinian Trachytes.

	A	B	Aa
SiO ₂	65.94	59.92	1.099
Al ₂ O ₃	16.11	14.30	.158
Fe ₂ O ₃	2.56	7.50	.016
FeO	0.82	0.42	.011
MgO	0.60	0.72	.015
CaO	1.06	1.90	.019
Na ₂ O	5.27	5.32	.085
K ₂ O	6.49	5.77	.069
H ₂ O +	0.25		
H ₂ O -	0.36	0.34	
TiO ₂	1.21	0.87	.015
P ₂ O ₅		0.58	
MnO	0.06	0.06	.001

100.73

A. Trachyte. Conca Cannas, near Uras, Monte Arci.

B. Trachyte. Nuraghe Terchis, Monte Muradu, near Macomer.
Includes 0.11 ZrO₂, 0.06 SO₃, 0.05 BaO.

The analysis of the Monte Arci rock is that of an ordinary trachyte, somewhat high in silica. It has no known counterpart among Sardinian lavas, the Monte Muradu trachyte approaching it most closely. It will be observed that in both of these ferric oxide is much higher than ferrous, and this seems to be connected with the occurrence of the peculiar yellow pyroxene, a point to be investigated later in connection with the older rock.

The norm of A is as follows:

Q	8.22
Or	38.36
Ab	44.54
An	1.11
Di	2.38
Hy	0.40
Il	1.67
Hm	2.56
Tn	0.78

The mode is essentially normative and, giving the small amounts of anorthite and titanite to the pyroxenes, would be roughly as follows:

Quartz	8
Soda-microcline	83
Pyroxene	6
Iron ores	3

Hypersthene Andesite (Dacose, II.4.2.4 and tonalose, II.4.3.4).

Andesitic lava flows were found overlying those of rhyolite in several places. Though they differ somewhat in chemical composition, especially as regards the amount of silica, they are much alike modally, and so had best be grouped and described together. They grade into the basalts, which are andesitic in character, but will be described separately.

One of the best exposures found is in the north wall of Canale Perdiera, near Uras. The lower 10 to 20 meters of this is a gray rhyolite, covered by rhyolitic tuffs and a sheet of light gray perlite. Above this is a thick (about 15 meters) coarsely columnar flow of rather coarse-grained, basaltic-looking andesite. On the same level as this, but cut off by a small side valley, is a slightly thicker flow of a fine-grained, dark red, basaltic rock (andesite). Above both there is a 40 to 50 meter thick flow, with well-developed columnar structure, of a quite granular, light gray andesite. This extends to the visible top of the cliff, though some fallen blocks of basalt indicate that a basalt flow covers the whole.

Flows of similar basaltic-looking andesite are met with covering the rhyolite in the two unnamed concas south of Conca su Ollastru, below the Rione Pranu Pira. What is probably a similar rock covers the ridge between Conca Perdiera and Conca Cannas, though the loss of the specimen renders it uncertain.

In the hand specimen these andesites look like basalts. They are all wholly devoid of phenocrysts. That which forms the visible upper flow of Canale Perdiera (analyzed below) is millimeter-grained, light gray, consisting of dark gray specks in a white to light gray base. The flow below it is finely mottled, of small black patches in an interstitial, pinkish brown, felsitic material. The red rock is a true brick-red, very fine-grained, aphanitic and compact, except for some small vesicles. The red color is due to weathering, but it extends to the center of the largest blocks examined and the whole flow, from top to bottom, is of the same uniform color. The blocks from the flows below Rione Pranu Pira are dark gray, almost black, fine-grained, aphanitic and compact. None of the specimens

show phenocrysts, except for some very rare, small, rounded crystals of feldspar.

Microscopically these rocks are seen to be hypersthene andesites and are referable to two distinct types; one holocrystalline, with ophitic texture, carrying considerable augite along with the hypersthene; the other vitrophyric with much hypersthene and very little augite.

The ophitic andesite is represented by the specimens from Canale Perdiera, except the red flow. The feldspar is labradorite, about Ab_3An_1 , in divergently arranged, rather thick, subhedral plates, with strongly marked twinning lamellae. These carry few inclusions, by far the greater part of the mafic minerals being intersertal between them. The hypersthene is colorless or gray, in subhedral stout prismoids or anhedral patches, with well-developed cleavage. It is almost entirely free from inclusions, containing rarely small magnetite grains. Colorless augite, distinguished from the hypersthene by its higher birefringence and oblique extinction, is almost invariably anhedral, either intersertal between the feldspar tables or forming a patchy border to the hypersthene, the augite individuals being much smaller than those of the orthorhombic pyroxene. Ores, either small irregular anhedral (magnetite) or in thin tables (ilmenite), are rather common, usually included in the augite. There are very few small anhedral of quartz, some small areas of micrographic quartz and feldspar, but no glass.

The vitrophyric type is best represented by a specimen from the second valley south of Conca su Ollastru. The abundant, diversely arranged small laths of feldspar are not more than $\cdot 1$ to $\cdot 2^{mm}$ long by one tenth as thick. They are all multiply twinned, with extinction angles which vary from Ab_3An_1 to Ab_1An_3 , and are consequently andesine. They are fairly free from inclusions, but are apt to carry thin glass cores. The hypersthene is more abundant and larger than the feldspars, as sharply defined but subhedral prisms, from $0\cdot 2$ to $1\cdot 0^{mm}$ long and about one tenth as thick. They are perfectly colorless, with well-defined cleavage cracks, uniformly parallel extinction, and quite free from inclusions in the center, though they are apt to have a fringe of very small magnetite grains along the border or be surrounded by a thin zone of colorless diopside. Colorless monoclinic pyroxene is much less abundant than in the preceding type. Apart from a few larger crystals ($0\cdot 5^{mm}$), rounded by magmatic corrosion, and with a later fringe of minute hypersthene needles, augite is present only as very small interstitial anhedral. Very small ($0\cdot 01^{mm}$) grains of magnetite are rather abundant, chiefly fringing the hypersthene, as mentioned above. Interstitial between the

andesine and hypersthene crystals is a base of colorless glass, which appears to be gray through the presence of much exceedingly fine black dust.

The brick red basaltic andesite from Canale Perdiera much resembles this, except that here the hypersthene uniformly have a yellowish brown, transparent border, which much resembles the iddingsite that surrounds some olivines. This border, which gives the rock its peculiar color, is obviously due to incipient alteration. The small augites are less liable to attack, and the feldspars are quite unaltered.

The chemical composition is represented by two analyses, with which are given for comparison two others made by me of pre-Tertiary andesitic flows.

Analyses of Sardinian Andesites.

	A	B	C	D	Aa	Ba
SiO ₂	61.08	56.34	60.14	56.60	1.018	.939
Al ₂ O ₃	13.66	13.95	16.65	16.80	.134	.137
Fe ₂ O ₃	0.70	1.94	2.94	2.52	.004	.012
FeO	5.61	6.73	2.39	5.12	.078	.093
MgO	4.69	6.41	1.16	3.80	.117	.160
CaO	4.84	6.20	5.21	7.29	.087	.111
Na ₂ O	3.84	3.10	3.41	2.43	.062	.050
K ₂ O	2.23	0.76	2.51	1.98	.023	.008
H ₂ O+	0.74	1.04	3.98	1.80		
H ₂ O—	0.49	0.63	0.54	0.58		
TiO ₂	1.76	2.22	0.62	0.99	.022	.028
P ₂ O ₅	0.17	0.44	0.07	0.12	.001	.003
MnO	---	---	0.06	0.13		
	99.81	99.79	99.68	100.16		

A. Hypersthene vitro-andesite. Below Rione Pranu Pira. Monte Arci.

B. Augite-hypersthene andesite, upper flow, Canale Perdiera, Monte Arci.

C. Augite vitro-andesite. Monte Furrù, near Bosa.

D. Augite andesite. Monte Piscinale, near Bosa.

Aa and Ba, mol numbers of A and B.

Apart from the low alumina and high titanium these analyses resemble those of many other andesites. It is of interest to compare them with the earlier flows a little farther north. With about the same silica, the two types differ in about the same way; the earlier having higher alumina, ferric oxide, lime and potash, with lower ferrous oxide, magnesia, soda, titanium and phosphorus. The relations will be discussed at length later, when more analyses are available.

The norms are as follows:

	A	B
Q-----	12.36	11.64
Or-----	12.79	4.45
Ab-----	32.49	26.20
An-----	13.62	21.96

Di	7.91	4.91
Hy	14.71	21.04
Mt	0.93	2.78
Il	3.34	4.26
Ap	0.34	1.01

According to these A falls in dacose with the full symbol II.4".2(3).4, and B in tonalose with the symbol II(III).4".3".4(5). These norms are of interest in showing the presence of about 12 per cent of excess silica. This is much more than is visible as quartz in the holocrystalline type (B), and must be present in the glass base in the other. Such an excess of silica is very commonly observed among the analyses of andesites, and these lavas generally show an excess of some 10 to 20 per cent. This silica is either not present at all or only in small part in the mode, and is to be regarded as "occult," to use a term recently proposed.*

Basalt (Andose, II.5.3.4).

Basalts formed the last lavas poured out by the volcano and they cover large extents of country around it, very much as they do at Monte Ferru. These flows are noted by della Marmora at many localities and were seen by me near Uras and Marrubiu along the west flank. They were always observed covering the rhyolites and other salic rocks, and were never covered by them. Della Marmora also mentions their occurrence as overlying the "trachytes," and he† describes the sheet which caps the rhyolites at the culminating points of the Trebinas. According to him‡ basaltic rocks also form dikes which cut Pliocene marls near Ales. These I did not see.

These basalts are very dark gray, almost or quite black, and very dense, either perfectly compact or showing only a few vesicles. Very small and rare feldspars are the only phenocrysts visible to the naked eye. The groundmass is quite aphanitic.

In thin section the specimens collected by me vary somewhat in texture as well as in mode.

That from the thick flow at Uras, an analysis of which is given beyond, is ophitic, composed of tables of labradorite (Ab_2An_2) with the usual twinning, and anhedral to subhedral grains of colorless pyroxene. Part of this is hypersthene and part diopside, the two being distinguishable by the extinction angles and birefringence, as in the andesites. Much of the pyroxene is apparently slightly altered, being of a yellow-

* J. P. Iddings, *Igneous Rocks*, ii, p. 19, 1913.

† Della Marmora, *op. cit.*, pp. 500 and 622.

‡ Della Marmora, *op. cit.*, p. 620.

brown color—this color sometimes extending through the whole crystal, and less often only partially. These pyroxenes look, at first sight, like olivines partly altered to iddingsite. A little alkali feldspar occurs in patches, but the interstitial material is mostly a black dusty substance, which high powers resolve into a colorless glass thickly crowded with minute, black, spherical globulites. As the usual ore grains are entirely lacking, these are probably of titaniferous magnetite. Only a few of the feldspars and still fewer of the pyroxenes are of such size as to be called phenocrysts.

Another type, represented by specimens from the Rione Muratta, near Canale Perdiera, and from Santa Suina chapel, is finer grained and decidedly andesitic or trachytic in texture. The feldspar tables are much smaller and thinner, are somewhat more sodic, and show a tendency to fluidal parallel arrangement. The colorless pyroxenes are nearly all of hypersthene, in small anhedral or subhedral prisms, and are not colored yellow as is the preceding type. Some euhedral to subhedral grains of olivine, with iddingsite borders, are present. Magnetite grains are rather common in this type. There is very little colorless interstitial glass. Except for the presence of olivine these basalts greatly resemble the andesites just described, and are best to be regarded as andesite-basalts.

Only one analysis was made of these rocks, there being given for comparison an analysis of a basalt from Monte Ferru and one from Ploaghe.

Analyses of Sardinian Basalts.

	A	B	C	D	Aa
SiO ₂	52.79	52.40	56.34	52.67	.880
Al ₂ O ₃	16.45	15.26	13.95	15.35	.161
Fe ₂ O ₃	2.74	0.74	1.94	3.82	.017
FeO	6.44	8.33	6.73	5.42	.089
MgO	5.56	7.45	6.41	4.40	.139
CaO	6.51	7.33	6.20	5.91	.116
Na ₂ O	3.64	3.54	3.10	4.50	.059
K ₂ O	1.21	0.99	0.76	2.68	.013
H ₂ O +	1.02	0.29	1.04	0.37	
H ₂ O —	0.21	0.06	0.63	0.14	
TiO ₂	2.64	3.12	2.22	4.04	.033
P ₂ O ₅	0.39	0.49	0.44	0.75	.003
MnO	0.06	0.08	---	trace	
NiO	0.18	0.06	---	none	.002
	99.84	100.14	99.76	100.05	

A. Uras, Monte Arci.

B. Near Cuglieri, Monte Ferru.

C. Andesite, Canale Perdiera, Monte Arci.

D. Basalt. Monte San Mateo, Ploaghe.

Aa. Mol numbers of A.

Q	4.50
Or	7.23
Ab	30.92
An	24.74
Di	3.80
Hy	17.22
Mt	3.92
Il	5.02
Ap	1.01

This places the Arci basalt in andose, with the symbol II".5.3.4", the Cuglieri basalt falling in the salemic homologue camptonose, "III.5.3.4", and that of Ploaghe in akerose, II.5.2.4. The mode is approximately normative. The quartz is occult in the glass base, and most of the normative magnetite and ilmenite is present in the black globulites. The normative hypersthene and diopside express very closely the modal relations of the orthorhombic and monoclinic pyroxenes. Judging from its color the latter can carry but little ferric iron. The mode may be roughly stated thus:

Quartz (occult)	4
Labradorite (Ab, An _s)	62
Diopside	5
Hypersthene	17
Ores	8
Apatite	1
Glass	3

General remarks.—As only a hasty glimpse was had of a part of the volcano, the data at hand do not warrant any lengthy discussion of the general character of its lavas. My slight examination was, however, sufficient to corroborate the statements of della Marmora and show that in structure it much resembles Monte Ferru, consisting of a domal core of rhyolites (possibly with phonolites), followed and covered by flows of trachyte, dacite and andesite, the whole closing with great outflows of rather andesitic basalts. It is noteworthy that tuffs and scoria beds are rare, just as they are at Monte Ferru, except in the initial stages.

So far as known the rocks are distinctly silicic, more so than at Ferru, where rhyolites are not known, but trachytes and phonolites are abundant. They are distinctly alkalic and mostly sodipotassic. These features find their modal expression in the absence of sodic pyroxenes and amphiboles, and the predominance of hypersthene over diopsidic pyroxene. Titanium is rather high and its amount increases regularly with decreasing silicity.

Geophysical Laboratory,
Carnegie Institution of Washington.

ART. LI.—*On the Use of Sealing Wax as a Source of Lime for the Wehnelt Cathode*; by NELLIE N. HORNOR.

IN the Wehnelt* cathode as first employed various metallic oxides were used as salts. Those of calcium, barium, and strontium gave an abnormally large discharge of negative electricity. The sign of the electrification depends upon the metal used and also upon the class of the salt.† Willows and Picton‡ used nickel and platinum strips for the cathode, while Richardson§ employed both the tube and strip methods, and recently Sheard|| used the tube method.

The conditions affecting the efficiency of this form of cathode have also been studied by Horton,¶ Garret,** and Wilson.†† In the work by Willows and Picton, referred to above, they found that when using a pressure of $\cdot 002^{\text{mm}}$ Hg and up, a voltage of 36, and a temperature of 1100 degrees Centigrade, there was a decided increase in the activity of the salt when the cathode had stood cold over a period of several days or weeks. They also found a greatly increased stream of electrons on making the discharge after it had been broken for a time, the heating current continued the while. The accumulation of electrons in the heated lime was dependent upon the interval of time.

It has been known for some time that ordinary sealing wax makes a fairly good source of lime. The Bank of England wax seems quite satisfactory. Its use, however, was until recently confined to the Cavendish laboratory. For some time it has been evident that its behavior as a lime is different than that of the oxides which are generally used. Hence the following investigation, in which the object is a study of the activity of this source of lime together with the various conditions best suited for its efficient working.

Description of Apparatus.

A sketch of the apparatus used is shown in fig. 1. *MN* is a two liter spherical flask, *S'* is a drying bulb, *B'* the heating circuit, *C* the cathode, and *A* the anode. The aluminium disc *G'* was connected through a reversing switch *K'* to the galvanometer.

* Phil. Mag., vol. x, July, 1905.

† J. J. Thomson, Proc. Camb. Phil. Soc., vol. xiv, 1906.

‡ Phys. Soc., London, Proc., June, 1911.

§ Phil. Mag., vol. xx, 1910.

|| Phil. Mag., vol. xxv, March, 1913.

¶ Phil. Trans. Sec. A, vol. ccvii, 1907.

** Phil. Mag., vol. xx, October, 1910.

†† Phil. Mag., vol. xxi, May, 1911.

meter and to earth. A high potential cabinet *T* furnished the voltage, the positive terminal was connected through a water resistance to earth and to the anode and the negative through

FIG. 1.

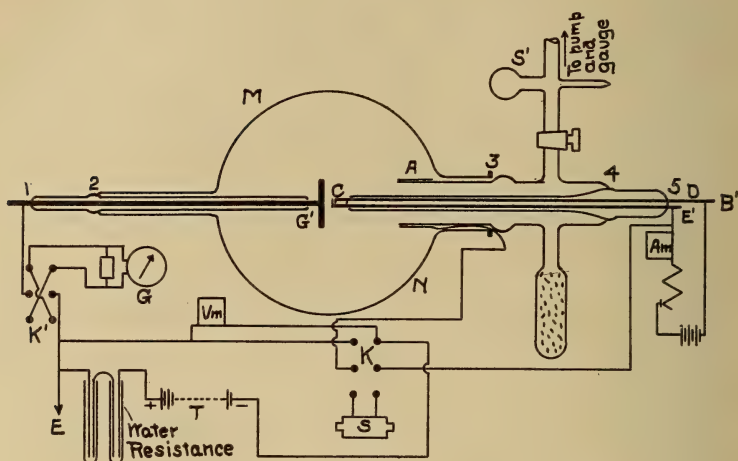
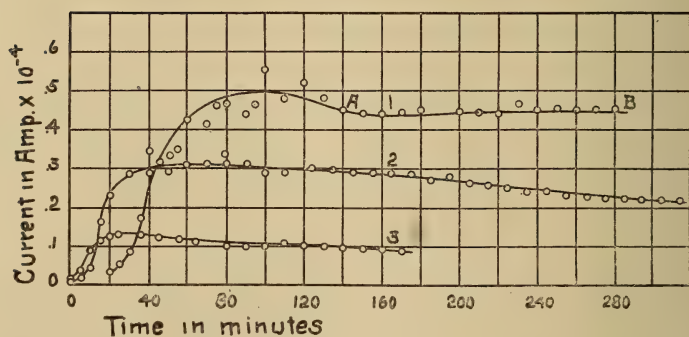


Fig. 1

FIG. 2.



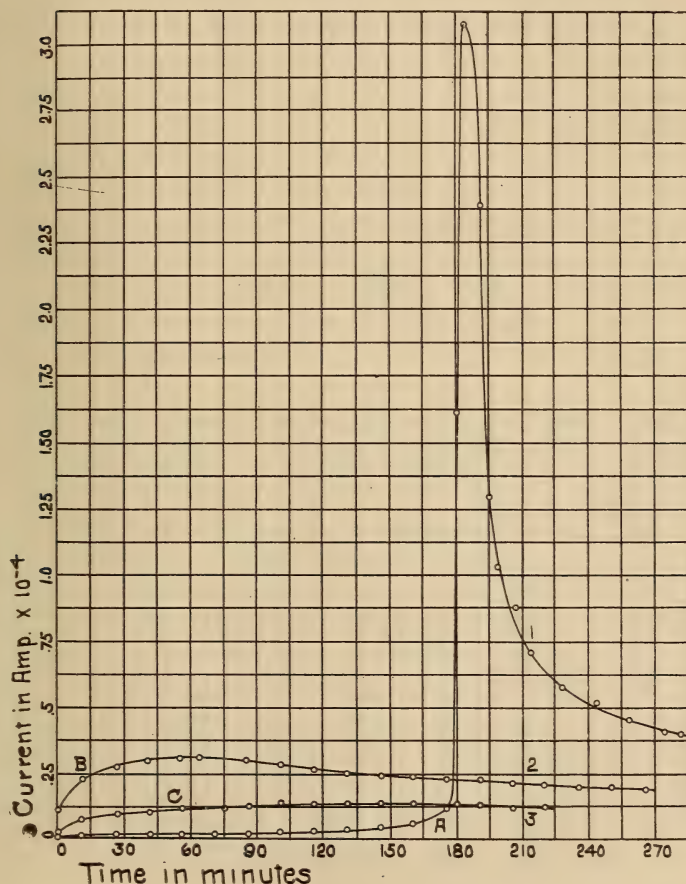
a switch *K* to the cathode. A voltmeter, *VM*, and an induction coil, *S*, were connected to the switch *K* as shown. 1, 2, 3, 4, and 5 are red wax joints. The method of mounting the cathode was that recently described by Knipp.* A Nalder D'Arsonval galvanometer, *G*, of a fair degree of sensitiveness was employed.

* Phys. Rev., vol. xxxiv, March, 1912.

Method.

The electrons fell upon the disc G' , located opposite and about 4^{mm} from the cathode, and the resulting current was indicated by the galvanometer. With each galvanometer reading, which was the mean of two deflections, the pressure,

FIG. 3.



discharge voltage, and heating current readings were taken. The heating current was kept strictly constant. The pressure was also kept practically constant by occasional pumping.

After mounting the platinum strip, a very small piece of the red wax was placed centrally upon it. The wires D and E' were then connected to the heating circuit and the current was

FIG. 4.

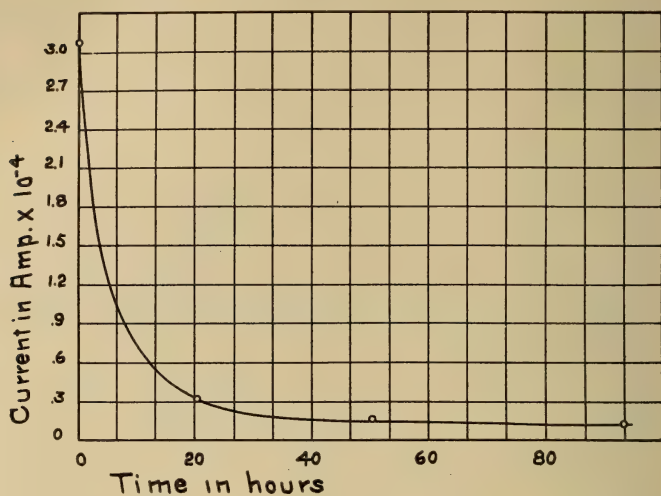
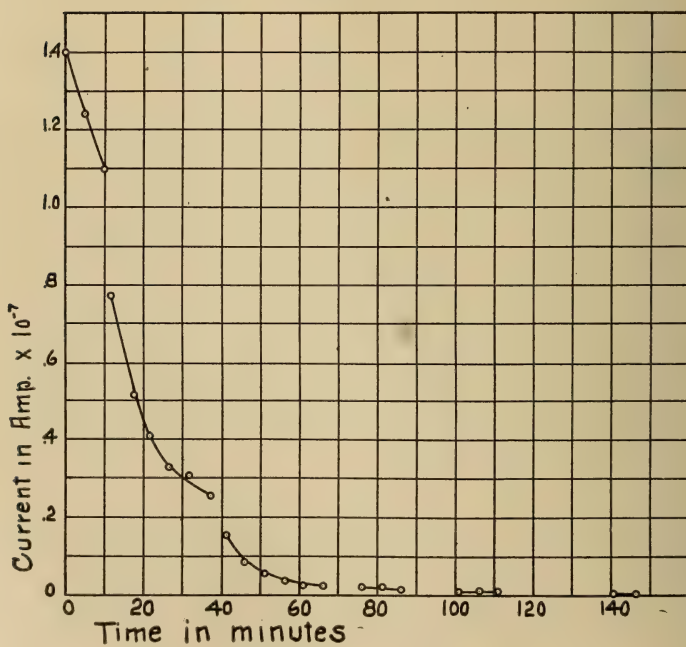


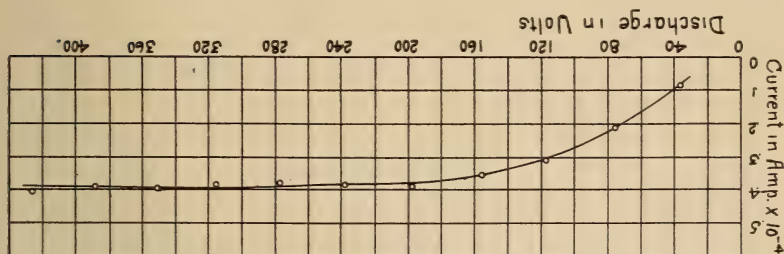
FIG. 5.



gradually increased until the disc of lime became white. The lime was thus deposited on the platinum strip. The tube was then placed in position, sealed, and the apparatus evacuated until the pressure was $\cdot 015^{\text{mm}}$ of mercury or less. Pressures ranging from $\cdot 003$ to $\cdot 04^{\text{mm}}$ were used. The apparatus was usually allowed to stand over night after evacuating to allow the P_2O_5 to absorb the moisture.

The heating current was adjusted until the temperature of the platinum was that corresponding to a light cherry-red.

FIG. 6.



Since it was necessary to renew the lime frequently, a reliable thermo-junction connection was nearly impossible and hence no attempt was made to determine the temperature. It was, however, kept strictly constant during any given run or set of runs. The discharge circuit was closed, the time noted, and the galvanometer watched for the current to start. When a cathode with fresh lime was heated the first time the discharge did not start immediately but only after from ten to thirty minutes if conditions were favorable. An induction coil may be used to start the discharge, but this complicates matters as there seems to be a gradual rise due to the ionization caused by the induction coil discharge. The cathode stream may also be started more quickly by making the heating current larger for a short time; however if this is done the increase to a maximum and the maximum itself are not shown,—only the part of the curve due to the decay is obtained.

Discussion of Curves.

The effect of changes in the heating current is shown by curve 1, fig. 2. A very small change in this current, in fact one which the eye could scarcely detect on the ammeter where two scale divisions read $1/10$ of an ampere, produced quite an appreciable effect upon the galvanometer deflections.

After two hours the heating current became fairly steady and a smooth curve, from *A* to *B*, was obtained. The cathode was allowed to stand cold with the vacuum up for two days. On heating to the same temperature and starting the discharge again the current rose to a maximum value in an hour and then remained comparatively steady for the rest of the run. The steady current value shown in curve 2, fig. 2, was very little smaller than the maximum, which in turn was much smaller than the steady value for the preceding run. After five days another run was made with the same platinum strip and lime heated to the same temperature. This run gave a maximum less than the steady value for the second run, as shown by curve 3. It has the same general characteristics as curve 2. The discharge voltage for these curves was approximately 400 volts, the heating current 4.63 amperes, and the pressure varied from $\cdot 005$ to $\cdot 016^{\text{mm}}$ Hg. In the last two curves the heating current was steady. The curves in fig. 2 indicate that the activity of the red wax decays with time. This is also shown in a striking manner by curves 1, 2, and 3, fig. 3. The maximum value of the current during any given run, after the lime had been cold from 1 to 4 days, was always less than the steady value of the current for the preceding run. Apparently when the lime is allowed to become cold it is not able to regain the activity it had at the end of the previous run. However, the activity that it does acquire it regains quickly.

The relation between the maxima and the number of hours between them is shown by fig. 4. Evidently these maxima decrease very rapidly at first.

When the lime is used for the first time it is very difficult to adjust the heating current to a value that will give smooth curves similar to 2 and 3 in fig. 2. The form of the curve is more likely to be that shown in curve 1, fig. 3. In this the number of electrons emitted for the first two and one-half hours increased very slowly, when suddenly it rose to a very high maximum and then almost as suddenly fell to a much lower steady value. The temperature was that corresponding to cherry-red. This sudden and very high maximum indicates that most of the electrons which may possibly be emitted under these conditions acquired sufficient energy to escape almost simultaneously and thus caused, as it were, an *explosion*. Curves 2 and 3, in fig. 3, again show the same characteristics as curves 2 and 3 in fig. 2. After the lime has once been heated, the subsequent currents start much more easily and rise to a maximum more quickly, suggesting that the electrons are in a state more favorable to emission. The beam was visible to the eye in curves 1, 2, and 3, fig. 3, from *A*, *B*, and *C* on.

If the discharge voltage was cut off while the heating con-

tinued, the current obtained on again closing the discharge circuit was in every case smaller than it was just before breaking. This is shown by fig. 5. The behavior of the lime seemed to be much the same as though it had been allowed to stand in the cold, except that the effect was not so pronounced. This shows that the decrease in activity for short intervals of no discharge was slight, yet definite, if the lime was kept hot. This result does not agree with that of Willows and Picton, who observed, for the salts that they used, a decided increase in activity under the same conditions.

Data on the saturation voltage were obtained as follows: for a given heating current and a discharge voltage of 40 volts the run was continued until the current became steady, after which the voltage was advanced by steps of 40 volts at intervals of 10 minutes, the maximum current being recorded each time. The curve in fig. 6 shows the results obtained. There was saturation at 200 volts.

The Bank of England wax upon analysis was found to have the following principal constituents: calcium sulphate (gypsum), barium sulphate (heavy spar), mercuric sulphide (cinabar), and shellac.

Summary.

It was shown that when Bank of England sealing wax is used as the source of lime there is a falling off in the activity with time.

When a maximum is reached most of the electrons are emitted during the first run.

When the discharge is broken while the heating current is maintained there is a slight falling off in the negative stream.

The above results are exactly opposite to those obtained by Willows and Picton using calcium oxide on a platinum strip, while they agree in part with the observations of Sheard, who found that the activity for cadmium iodide and iodine, with the tube method, decreased during any given run.

The saturation voltage was found to be 200 volts.

There was a falling off in the maxima for successive runs, and the steady current for any given run was usually much smaller than that for the preceding run with the same lime.

In conclusion, the writer takes pleasure in thanking Professor A. P. Carman for the facilities of the department, and Dr. C. T. Knipp for suggesting the problem and assistance in carrying out the details of this investigation.

Physical Laboratory,
University of Illinois.

ART. LII.—*The Dehydration and Recovery of Silica in Analysis*; by F. A. GOOCH, F. C. RECKERT and S. B. KUZIRIAN.

[Contributions from the Kent Chemical Laboratory of Yale University—celii]

The Dehydration of Silica.

THE question as to the temperature which must be applied, and of the duration of the ignition necessary to bring silica to a constant weight in the analysis of silicates, has been the subject of much investigation and discussion. The opinion is general* that in order to obtain the correct weight of anhydrous silica derived by precipitation in the usual course of analysis, and ignition, the temperature employed must be that of the blast lamp. Lunge and Milberg† have shown, however, that silica obtained by hydrolyzing silicon fluoride sustains after ignition in the full flame of a good Bunsen burner no further appreciable loss upon application of the blast heat, and these results have been confirmed by Lohöfer‡ in Lunge's laboratory, and by Hillebrand, for silica thus derived from silicon fluoride. On the other hand, Hillebrand found in the case of silica derived by fusing quartz with sodium carbonate, treating the product with hydrochloric acid, and evaporating three times, with intermediate extractions and filtrations, that constant weights were obtainable only by blasting, and that blasting for half an hour (as is generally recommended) is often insufficient to secure constancy of weight. Quartz powder was used as the source of the silica in Hillebrand's experiments, and this was found to be 99.88 per cent pure, by careful treatment with sulphuric and hydrofluoric acids.

It has been shown recently in certain experiments by B. H. Walker and J. B. Wilson§ that silica precipitated by acid may be brought to a constant weight by prolonged ignition over the Bunsen burner, thus avoiding the danger of loss which may occur when platinum is submitted to prolonged ignition with the blast lamp. Three hours is the minimum period mentioned as requisite. It is to be noted, however, that in these experiments no test was made for impurity in the residue after ignition, and that, as will appear from the work to be described, the main source of trouble in bringing precipitated silica to a constant weight does not lie in the process of dehydration in ignition, but is due to the presence of an impurity

* Hillebrand, Jour. Amer. Chem. Soc., xxiv, 371; Treadwell, Quant. Anal. trans. Hall, 3d ed., p. 486.

† Zeit. angew. Chem., 1897, 425.

‡ Cf. Hillebrand, loc. cit.

§ U. S. Geol. Survey, Circular No. 101, August 16, 1912.

which must either be volatilized or made to enter into stable chemical relation with the silica. From the results of certain experiments to be detailed it will appear that, while prolonged ignition with the Bunsen burner or with the blast lamp may sometimes be necessary to secure constant weights of silica separated from an alkali silicate by the action of hydrochloric acid, when the difficulty of securing constant weights appears it is to be attributed to the inclusion of foreign material more or less volatile and changeable at high heat, and not to the obstinate retention of water by the silica.

The original material taken for our experiments was a commercial "analyzed" hydrous silicic acid containing approximately from 45 to 50 per cent of anhydrous silica according to the degree of exposure. When digested with boiling water this material yielded traces of a soluble chloride and soluble sulphate. After the ignition of portions of the original substance—from 0.5 grm. to 5 grms.—for fifteen minutes over a large Bunsen burner, traces of chloride or sulphate could be still detected in the silica. When similar portions of the original substance were ignited over the burner for forty-five minutes or over the blast lamp for half an hour neither chloride nor sulphate was found in the aqueous extraction of the residue, but treatment with sulphuric acid left a residue which amounted in the average to 0.24 per cent of the original substance. The barium sulphate precipitable by barium chloride from the solution of this residue proved to be nearly equivalent to the entire residue counted as sodium sulphate. Inasmuch as neither chloride nor sulphate could be found in this strongly ignited silica, it may be presumed that sodium oxide, remaining in combination with the silica, constituted, at least after the strong ignition, the impurity which after the treatment with the acids appeared in the form of sodium sulphate. Upon this presumption, the silica used was 99.92 per cent pure after the strong ignition. The record of experiments in which portions of the hydrous silica were heated during successive half-hour periods, with the Bunsen burner and with the blast lamp, is given in the following table. These results show plainly that the silica used may be brought to a practically constant weight in half-hour ignitions with a good-sized Bunsen burner.

The next experiments show the effects of treating similarly the product obtained by fusion of the ignited silica with sodium carbonate, treatment with hydrochloric acid, evaporation, extraction with very dilute hydrochloric acid, and careful washing. In series A of these experiments the drying was effected at 110° in the air bath. In series B the residue obtained by evaporation to apparent dryness on the steam bath

TABLE I.

Ignition of Commercial, "Analyzed" Silica.

Hydrous Silica taken (Approximate weight)	Weight of SiO ₂ found				
	After heating with the Bunsen burner, in half-hour heats		After heating with the blast lamp in 15 minute heats		
gram.	I gram.	II gram.	I gram.	II gram.	III gram.
	A				
0.2	0.1008	0.1006	0.1006		
0.4	0.1930	0.1929	0.1926		
0.4	0.1968		0.1967	0.1966	
0.5	0.2501		0.2500	0.2500	
1.0	0.4568		0.4568	0.4568	
1.1	0.5343		0.5333	0.5330	0.5330
1.1	0.5309	0.5304	0.5306	0.5302	0.5302
1.1	0.5325	0.5327	0.5323	0.5324	
1.1	0.5374		0.5372	0.5373	
1.1	0.5392		0.5381	0.5381	
1.1	0.5353		0.5351	0.5347	0.5347
	B				
1.0	0.5464	0.5454	0.5447	0.5445	0.5444*
1.0	0.5206	0.5204	0.5202	0.5202	0.5202
1.0	0.5447	0.5443	0.5441	0.5439	0.5439*
1.0	0.5346	0.5346	0.5342	0.5342	0.5342
1.0	0.5427	0.5427	0.5427	0.5427	-----
1.0	0.5376	0.5373	0.5373	0.5372	-----
1.0	0.5511	0.5511	0.5511	0.5511	-----
1.0	0.5445	0.5445	0.5444	0.5443	-----
1.0	0.5344	0.5343	0.5340	0.5338	0.5338
1.0	0.5513	0.5513	0.5513	0.5512	-----
1.0	0.5312	0.5312	0.5311	0.5311	-----
1.0	0.5536	0.5536	0.5531	0.5531	-----

was moistened with acetic anhydride and warmed over a radiator until this reagent fumed freely, the object of this treatment being to thoroughly desiccate the silica while preventing the otherwise possible formation of sodium silicate by action between silica, included sodium chloride, and water. Each of these methods of treatment leaves the silica drier, more porous, and, therefore, more effectively washable than is the case when drying is brought about by the steam bath only. The results of these experiments are given in the following table. Every residue of silica was treated, after the final ignition, with sulphuric acid and hydrofluoric acid, the amount of sodium sulphate remaining was weighed, and the equivalent weight of the combined sodium oxide was calculated.

* It was found that the crucible used in this determination was subject to loss when ignited by itself over the blast lamp.

TABLE II.

Ignition of silica separated by acid after fusion with sodium carbonate.

Residue of SiO ₂ after ignition with Bunsen burner gram.	Residue of SiO ₂ after subsequent ignition with blast lamp gram.	Loss on ignition with the blast lamp gram.	Na ₂ CO ₃ used in the fusion gram.	Residue after H ₂ SO ₄ + HF treatment Na ₂ SO ₄ } = { Na ₂ O gram. } { gram.
------------------------------------------------------------------------------------	--------------------------------------------------------------------------------------------	--------------------------------------------------------	-------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------

A

Residue dried at 110°.

0.5300	0.5291				
	0.5290				
	0.5287	0.0013	4	0.0009	0.0004
0.5380	0.5373				
	0.5368				
	0.5365				
	0.5363				
	0.5363	0.0017	4	0.0010	0.0004
0.5365	0.5360	0.0005	4	0.0011	0.0004
0.4583	0.4575	0.0008	4	0.0014	0.0006
0.5071	0.5068	0.0003	4	0.0015	0.0006
0.5166	0.5159	0.0007	4	0.0012	0.0005

B

Residue dehydrated on steam bath and heated with acetic anhydride.

0.1984					
0.1980	0.1977	0.0007	2	0.0016	0.0006
0.4566*	0.4564				
	0.4562	0.0004	4	0.0020	0.0008
-----	0.5322		4		
	0.5325				
	0.5325	0.0003		0.0010	0.0004

A comparison of these results with those of Hillebrand, to which reference has been made above, points to the conclusion, that the more perfect drying of the silica before attempting the process of extraction and washing, results in smaller losses when the residue which has been ignited over the Bunsen burner is subjected to the heat of the blast lamp. This fact suggests that the better desiccation is conducive to the more nearly complete washing of soluble material from the precipitated silica. At the best, however, the separation of foreign matter is not perfect, and the presence of material which is difficultly volatilized is sufficient to account for the slight changes in weight observed when the silica ignited with the Bunsen burner is submitted to further heating with the blast flame. According to our experience, therefore, the difficulty in bring-

* Ignition extended to one hour.

ing to a constant weight the silica precipitated in the ordinary way, by the action of acid upon the products of fusion with an alkali carbonate, is not due to the obstinate retention of water but to the presence of foreign material difficultly volatile or slowly changeable at the temperature of ignition. In our experiments, the foreign material retained in the precipitated silica must have been sodium chloride, and this in the process of ignition of hydrous silica is, as we have found experimentally, converted by the action of water to sodium oxide, which combines with the silica. In the experiments described above, the sodium oxide retained by 0.5 grm. of silica amounted in the average to 0.0005 grm. After the treatment with sulphuric acid and hydrofluoric acid, the residue ignited at red heat is sodium sulphate, and from the weight found of this substance the equivalent weight of sodium oxide must be calculated in order that it may be used as the correction for the foreign material included in the silica as weighed. In the final ignition the use of the high heat of the blast lamp is not advisable, lest the sodium sulphate lose weight and so vitiate the correction to be applied to the silica.

The Recovery of Silica after Fusion with Sodium Carbonate.

It is a generally recognized fact* that, after fusion with sodium carbonate, silica cannot be recovered completely by a single filtration following any number of evaporations and treatments with hydrochloric acid. To secure satisfactory results it is necessary to evaporate the filtrate after the removal of the main amount of silica by the first treatment, treat the residue with hydrochloric acid, and again filter.

The experiments detailed in the following table record the results obtained in recovering silica by two such treatments after fusion with 3 grm. of sodium carbonate. The fused mass was treated with hydrochloric acid; the liquid was evaporated on the steam bath; the residue, desiccated either at 110° in the air bath or by the treatment with acetic anhydride, according to the method and for the purpose, previously described,† was extracted with hydrochloric acid; the insoluble silica was filtered off, washed, ignited, and weighed; the filtrate from the silica insoluble in this first operation was evaporated; and the residue obtained was treated like the first residue.

In these experiments the deficiency in silica found after the first thorough evaporation and desiccation at 110° amounts in the average to 0.0051 grm., after correcting for silica introduced in the sodium carbonate, and this is practically the

* Hillebrand, *Am. Chem. Jour.*, xxiv, 366: Treadwell, *loc. cit.*

† See p. 599.

TABLE III.
Recovery of Silica in Two Treatments.

SILICA TAKEN.

After ignition with Bunsen burner half-hour periods grm.	After ignition with blast lamp 15 min. periods grm.	Corrected for impurity (99.92 per cent. pure) grm.
-------------------------------------------------------------	--------------------------------------------------------	-------------------------------------------------------

SILICA RECOVERED.

FIRST TREATMENT.			SECOND TREATMENT.			TOTAL SILICA.	
Ignited with Bunsen burner grm.	Ignited with blast lamp 15 min. periods grm.	Corrected by $\text{HF} + \text{H}_2\text{SO}_4$ Process grm.	Ignited with Bunsen burner grm.	Ignited with blast lamp 15 min. periods grm.	Corrected by $\text{HF} + \text{H}_2\text{SO}_4$ grm.	Found grm.	Corrected for SiO_2 in Na_2CO_3 used* grm.

Desiccation at 110° .

A							
0.5309	0.5306	0.5300	0.5291	0.0023	0.0023	0.5297	0.5292
0.5304	0.5302	0.5298	0.5287				— 0.0006
B							
0.5215	0.5211	0.5164	0.5161				
0.5213	0.5211	0.5162	0.5160	0.0077	0.0077	0.5215	0.5211
0.5456	0.5450	0.5211	0.5150				+ 0.0004
0.5452	0.5448	0.5425	0.5420				
		0.5425	0.5418	0.0057	0.0055	0.5460	0.5456
0.5355	0.5448	0.5416	0.5412				+ 0.0012†
	0.5351	0.5295	0.5295				
	0.5351	0.5300	0.5293	0.0050	0.0050	0.5339	0.5335
0.5436	0.5436	0.5376	0.5370				— 0.0012
0.5436	0.5436	0.5371	0.5365	0.0080	0.0080	0.5430	0.5426
		0.5363	0.5358				— 0.0006

Desiccation at 137° by Acetic Anhydride.

A							
0.4568	0.4568	0.4566	0.4564	0.0008	0.0006	0.4558	0.4553
	0.4568		0.4562				— 0.0010
B							
0.5520	0.5520	0.5460	0.5440	0.0070	0.0068	0.5504	0.5500
0.5520	0.5520	0.5460	0.5440				— 0.0016
0.5454	0.5453	0.5403	0.5398				
0.5454	0.5452	0.5401	0.5398	0.0070	0.0065	0.5451	0.5447
0.5353	0.5349		0.5396				— 0.0001
0.5352	0.5347	0.5275	0.5270				
	0.5347	0.5272	0.5270	0.0075	0.0075	0.5338	0.5334
0.5522	0.5522	0.5465	0.5460				— 0.0009
0.5522	0.5521	0.5465	0.5459	0.0058	0.0056	0.5506	0.5502
		0.5453	0.5453				— 0.0015

† It was found that the crucible used in the preliminary ignition was subject to loss on ignition over the blast lamp.

*0.00013 SiO_2 in 1 grm. Na_2CO_3 .

amount of silica recovered in the second treatment. In the experiments in which acetic anhydride (B.P. 137°) was used to moisten the residue (after thorough desiccation on the steam bath) and then partially removed by boiling, the average deficiency in silica after the first treatment amounted to 0.0061 grm., and the amount recovered in the second treatment to 0.0051 grm. Obviously, the insolubility of the silica, after the process of desiccation, extraction, and filtration depends very largely upon the thoroughness of the drying; and, while the drying at 110° or at 137° (in acetic anhydride) greatly diminishes the solubility of the silica as compared with that of the substance when simply dried on the steam bath, the treatment with acetic anhydride offers no advantage over the process of drying in the air bath at 110° , at least, when the contaminating substance is sodium chloride.

The slight variations in the weights obtained when residues which had been ignited with the Bunsen burner were submitted to the temperature of the blast lamp appear to be due to the presence of sodium chloride which by strong ignition is either transformed to sodium silicate or is partially volatilized.

ART. LIII.—*The Ascent of Lava*; by FRANK A. PERRET.

WHY does the lava rise from below toward the earth's surface?

This fundamental question resolves itself, upon examination, into several parts. We may ask, for instance, why the lava should move in *any* direction,—why, that is to say, there should be motion of translation in this material,—why it should seek to extend itself from the position it occupies? But,—whether by reason of the pressure to which it may be subjected, or through actual augmentation of its substance, or by the absorption of infiltrating materials, or even through greater fluidity resulting from some *lessening* of pressures,—we know the magma to be endowed with the property and power of *expansivity*, in consequence of which it must, if possible, find or form for itself an outlet through its too restricting boundaries.

Nor, in view of this quality of expansiveness, shall we marvel that the magma should rise into a fissure which may open above the stratum or pocket which constitutes the reservoir. Assuming such injections to be abyssal, they will not, in general, perforate the outermost shells but, whether remaining as simple, lava-filled rifts or developing the expanded, top-like sections imagined by Johnston-Lavis* and Daly,† they will constitute secondary reservoirs nearer to, but not yet in communication with, the surface. It is from this point that the further progress of the lava forms the subject of our inquiry,—why, of all possible directions, this should still be upward or, more precisely, outward from the direction of the earth's center toward its periphery?

Such further progress is effected, in general, by a progress of *trepanning*, so to speak, which results in the formation of a vertical tunnel, often of exceedingly small diameter in proportion to its length.

But, if we remember that the rising of the lava represents work against gravity and necessitates the perforation of successive strata, and that, furthermore, the progression takes place at the point farthest from the heat reservoir and where the actual contact pressure is least, it would almost appear, at first sight, that, in ascending as it does, the lava follows the path of greatest resistance and advances where its power to do so is most limited.

* H. J. Johnston-Lavis: *The Mechanism of Volcanic Action*, Geological Magazine, London, October, 1909.

† Reginald A. Daly: *Abyssal Injection as a Causal Condition and as an Effect of Mountain-Building*, this Journal, Sept., 1906.

In seeking to explain these anomalies we may safely assume two things, viz., some guiding principle or directive force, which determines and maintains the upward direction of progress as a compass points to the north ; and, second, some mode of action,—some excavating agent other than simple heat and pressure,—which has not yet been considered.

Beginning with the latter, we may ask ourselves if there is anything at the upper level, where the progression takes place, which is not to be found at the other contact surfaces ? The answer is—gas.

We have here another demonstration, and a notable one, of the importance of the gaseous element in the dynamics of vol-

FIG. 1.



FIG. 1. Lava column with compressed gaseous head, fluxing its way upward through solid strata.

canic action. If the lava were a simple liquid and its function purely hydrostatic, as has sometimes been contended, the upward progression, as observed, could not occur. It is the escape of free gas which results, as we shall see, in the formation of the tunnel, but before taking up that phase of the subject, we may realize that we have also discovered the guiding principle—the directive force which determines and maintains the upward way. This lies in the *gravitative adjustment of gas and lava*,—the gas, by its lightness, places itself above the lava and, constituting, as it does, the active boring agent, the direction of progression will and must be upward ; nothing could be simpler.

As to the *modus operandi* of this trepanning by the gas-headed lava, it is obvious that we must consider the nature of the material to be perforated. If this consists of strata of solid rock the gases will be largely retained above the lava column

as a small, compressed plug. Daly has pointed out* the powerful heating effect of such compression, by which the gas acquires a true fluxing power, melting the contact walls. The fused material absorbs gas, adding heat of solution and of chemical reaction. The gaseous head of the lava column thus becomes an effective means of progression, capable of fluxing its way through the hardest strata. Examples of this action on a small scale may be seen in the many little pit-craters at

FIG. 2.

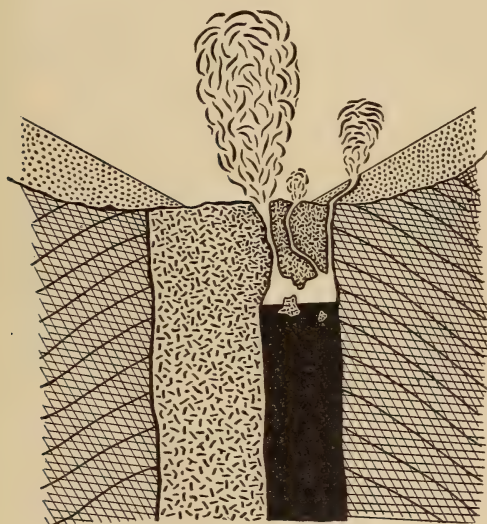


FIG. 2. Lava column with expanding gaseous head, eating its way upward through incoherent material.

Kilauea, which are simple, cylindrical channels rising vertically through the solid lava strata.

If, on the other hand, the ascent of lava is through a conglomerate mass of more or less incoherent materials, it is certain that the gases cannot be so perfectly retained and compressed above the column of lava. In such a case their action will be excavative, disintegrative, corrosive. Channels will be enlarged, masses dislodged and engulfed; and this "stopping" process will be combined with the peculiarly destructive effects of *fumarolic* activity. In contradistinction to the former method of temperature development, this is here maintained by the

* Reginald A. Daly; *The Nature of Volcanic Action*, Proc. Amer. Acad. Sci., vol. xlvii, No. 3, p. 93.

flow of gas through the lava column, thus continuously bringing up heat from below.

In fig. 2 the lava is represented as eating its way upward through the chaotic materials obstructing the conduit of a volcano as the result of the last eruption—the lava rising to re-establish communication with the crater and inaugurate a new eruptive phase after a period of repose. The sketch reproduces the actual condition of Vesuvius where, after seven years of external repose, during which time the conduit has been blocked, the lava has, at last, virtually reached the crater. Its gradual approach, by the process here described, has for many months been visibly manifested by a progressive increase in the temperature and volume of the fumarolic emanations at the crater bottom and especially by repeated *collapses* indicative of the subterranean stoping.

We may conclude that the progression of a lava column and its direction are determined by the gaseous emanation.

Posillipo, Naples, September, 1913.

ART. LIV.—*Solar Radiation*; by FRANK W. VERY.

THERE are two modes of measuring solar radiation which may be called the actinometric and the bolometric modes. The former measures the intensity of the total normal radiation on unit surface and is the more direct of the two. The bolometric method traces the distribution of energy in the solar spectrum, determines the wave-length of the maximum point in the spectral energy-curve, and infers by theory the temperature and radiating power of the solar surface, from which the intensity of radiation at the earth's distance is at once known, since the radiant energy diminishes in inverse proportion to the squares of sun's radius and earth's distance which on the average is given by the formula

$$\log (R/D)^2 = 5.33535 - 10.*$$

Both methods require a knowledge of the corrections to be applied for instrumental errors and for absorption by the earth's atmosphere.

There are now several reliable actinometers, capable, when properly handled, of giving results correct to 1 or 2 per cent. Unfortunately, some of these instruments may give readings which are as much as 20 per cent in error when inefficiently manipulated, or imperfectly corrected. The prime necessity, after the attainment of a moderate amount of skill, is that the observer shall make a thorough study of the theory of his instrument, become familiar with the necessary precautions, measure the instrumental constants with the greatest attainable precision, and apply all of the corrections indicated by theory which have a sensible magnitude.

The spectrobolometric method, invented by Langley and now perfected by the observers at the Smithsonian Institution, has corrections which are more complicated than those of the actinometer, but with reasonable precautions either method may now be put on a tolerably safe basis as far as the instrumental corrections are concerned.

The corrections for atmospheric interference with the radiant transmission are in an altogether different category. Hypotheses and mathematical discussions are required, and when all is done that human ingenuity can accomplish, the final result can hardly be dignified as a "measurement" of a "solar constant," but must be conceded to be scarcely more

* The distance-factor for any given date may be obtained by taking the semidiameter of the sun which is given for each day of the year in the solar ephemeris, looking out the log sine of this angle and doubling it, and subtracting from the above logarithm.

than a moderately close estimate at the best, or than a very unfortunate guess at the worst. The ablest investigators, and those whose opinions on the subject deserve the greatest weight, have said either that the solar constant can never be found in any exactly mathematical sense, or that its value is best stated with a very wide margin of probable error.

Of the two methods named, the second is least encumbered by difficulties from transmissive theory, and though circumlocutory, it is in many respects to be preferred. The radiant losses which are most difficult to estimate are those which affect all wave-lengths equally, or nearly so. But these losses make very little change in the *form* of the spectral energy-curve, and the position of the maximum energy ($\lambda_{\max.}$) will scarcely be altered by their neglect. In fact, the chief source of uneasiness to the investigator of the spectrum lies in the possible existence of a diffuse atmospheric absorption band very near to this maximum ordinate of the spectral energy-curve. There is considerable evidence of just such a band, and a variable one at that; but conceding that some, at any rate, of the observations may have escaped fatal infection from this source, and admitting that there are probably no better curves than those which have been published by Abbot and Fowle, of which a sample is given in figure 26 of Abbot's work on "The Sun," we may push this method for all it is worth. I can not do better than to quote from the last-mentioned work; but first let me call attention to the following point.

In a publication on "The Solar Constant"* I noted that the extreme infra-red spectrum is much more intense than would be expected from a theoretical spectral energy-curve, for such temperatures as are indicated by the position of maximum energy in the spectrum, and I attributed this divergence to the fact that the solar radiation is the sum of emissions from layers at various depths and having a wide range of temperature. Thus the very intense radiations of short wave-length from the deeper layers are greatly absorbed by more elevated layers of the solar atmosphere, which are heated thereby and radiate in turn, but at a lower temperature and longer wave-length, besides transmitting the long-waved emissions from the deeper layers more freely, so that the long waves escape more readily than the short ones. This peculiarity may also be due in part to the predominance in the sun of metals having positive coefficients of resistance which radiate long infra-red waves at high temperatures with greater intensity than black substances do, or which more nearly approach the ideal "black" radiator

* U. S. Weather Bureau Publication, No. 254, pp. 22-23, 1901.

in this part of the spectrum than lampblack and similar substances, which are reputed black for the shorter waves, but become transparent and less perfect radiators in the extreme infra-red, whereas metals at high temperatures become transparent for the short waves of the visible spectrum. Although not extending to as great wave-lengths as those on which my conclusions were based, these bolographs by the Smithsonian observers confirm the statement in a general way. The bolometric method which rests on the *shape* of the spectral energy-curve, obviously tends to underrate the solar temperature by overestimating the importance of the longer waves, and shifting the maximum in their direction.

Referring to the distribution of energy computed by the Wien-Planck formula for temperatures 7000° and 6200° Abs. C., Mr. Abbot says of the observed curves: "Their infra-red parts correspond to much hotter sources than do their visible and ultra-violet parts. It is evident, however, that the 7000° curve, except in the ultra-violet, is a better match for the observations than the 6200° curve" (The Sun, p. 112). On page 114 (*op. cit.*), the solar temperature is said to be "certainly above 6200° , and possibly near 7000° "; and on page 420, "it seems most probable that the photospheric* temperature should be set not lower than 6500° Absolute."

We shall not be far from the truth if we take the effective solar temperature as 6800° Abs. C., which gives for the solar constant at the earth's mean distance by Stefan's law,

$$A = (6800)^4 \times 1.267 \times (10)^{-12} \times 60 \times \sin^2 15' 59''.63 \\ = 3.518 \text{ gram cal. / sq. cm. min.}$$

This value is in close agreement with that which I have given in my paper, "A High-level Measurement of Solar Radiation,"† founded on an observation by Violle, and with concordant values which are obtained in my paper, "A Criterion of Accuracy in Measurements of Atmospheric Transmission of Solar Radiation,"‡ from observations by Savélieff and by Kimball, when treated by a modification of Crova's method. The latter values have been obtained by actinometric modes which are thus shown to be capable of yielding correct results when prop-

* Although continuing to use the word "photospheric," Mr. Abbot rejects the usual conception of a layer of opaque, incandescent cloud at a definite level, and holds that the solar radiation comes entirely from layers of relatively, but still imperfectly, transparent gas at various depths; that is to say, he denies that there is any basal layer giving a continuous spectrum, or any continuous spectrum other than a virtual one produced by the broadening of gaseous emission lines through pressure. This point needs separate discussion, which can not be attempted here. It is sufficient to note that the "photospheric" temperature in the above quotation is not distinguished from the effective solar temperature.

† Astrophysical Journal, vol. xxxvii, p. 25, January, 1913.

‡ Ibid., p. 31, January, 1913.

erly reduced; but it is impossible to reach even approximations to the truth by such methods of reduction as have been used by Pouillet, or by Abbot and Fowle. The neglect of the diurnal variation of atmospheric quality, and the erroneous supposition that the same coefficient of transmission can be used at all hours of the day, completely vitiates these reductions. Having obtained in this way a supposed solar constant of 1.95 cal./sq. cm. min., Mr. Abbot says: "From this, $T = 5860^{\circ}$ Absolute C. As this value falls below those obtained previously [by the bolometric method], we may suppose the sun's constant of emission is a little less than that of a perfect radiator."* This may indeed be the case, and the exponent of T in Stefan's law possibly differs somewhat from 4 for a body of solar composition and temperature, but if the hypothesis that the sun is a perfect radiator can be tolerated for Mr. Abbot's use in the bolometric computation, it ought to be good enough for the actinometric one. To use the hypothesis in the one case, and reject it in the other, is not admissible; and the discrepancy between the temperatures computed on this basis remains as a contradiction which overthrows the alleged determination of the solar constant to three significant figures. Warned by this example, we shall perhaps do well not to attempt the assignment of a definite value to the solar constant at the present time further than to say that it probably lies between 3 and 4, and apparently not far from 3.5 or 3.6 gram cal./sq. cm. min.

If we take the spectral energy-curve of the center of the solar disk, corrected for instrumental errors and approximately for the absorption of the earth's atmosphere, to get relative values which are correct as far as the ratios for different wavelengths are concerned, the maximum ordinate according to Abbot† is $\lambda_{\max.} = 0.458\mu$. Applying to this curve the appropriate coefficients of transmission by the sun's atmosphere,‡ we get the results given in the following table:

λ	0.3μ	0.4μ	0.5μ	0.6μ	0.7μ	0.8μ	0.9μ	1.0μ	1.5μ	2.0μ
a	0.008	0.372	0.490	0.405	0.308	0.226	0.157	0.120	0.051	0.018
b	0.05	0.18	0.29	0.37	0.43	0.475	0.51	0.54	0.64	0.69
c	0.16	2.07	1.69	1.09	0.72	0.48	0.31	0.22	0.08	0.03

For curve c , $\lambda_{\max} = 0.41\mu$.

* Op. cit., p. 114.

† The Sun, figure 26, page 109.

‡ Frank W. Very: "The Absorptive Power of the Solar Atmosphere"—Miscellaneous Papers of the Allegheny Observatory, New Series, No. 9, Table 5, p. 18.

where λ = wave-lengths, a = ordinates in the spectral energy-curve for the center of the solar disk (Abbot), b = transmission by the solar "atmosphere" (Very), $c = a/b$, or the photospheric ordinates which would be observed if the sun's "atmosphere" * above the photosphere could be removed.

The wave-length of the photospheric maximum differs very little from a similar, unpublished reduction of these measures made in the summer of 1882 at the Allegheny Observatory during Director Langley's absence in England, where he announced at the Royal Institution his theory of the "blue sun." If my measures had been made sooner, the form of this announcement would have been a little different, for upon recombining the spectrum colors in the proportions required to reconstitute a light equivalent to unabsorbed sunlight, I actually obtained a delicate tint of lavender, instead of blue. These provisional values of absorption by a species of solar atmosphere were accepted by Langley at that time, although some singular relations between the apparent absorption at different radial distances remained outstanding, which are now partially explained in several papers by Professor Schuster and myself, even if it is not possible to assign definite limits to several distinct yet probably simultaneously commingled processes.†

Since Mr. Abbot has recently obtained similar curves showing a great diminution in the radiation of short wave-length between the center and limb of the solar disk,‡ perhaps the reason why he has not applied this knowledge in reproducing the energy-curve of the photospheric radiation may be his unbelief in the reality of the photosphere. My result is given for whatever it may be worth and indicates a *photospheric* temperature.

$$T = 2930/0.41 = 7146^{\circ} \text{ Abs. C.}\S$$

Owing to the total absorption of the shorter ultra-violet waves by the atmospheres of either sun or earth, the losses of these radiations are somewhat problematical, and both the restoration and the resulting temperature are liable to be underrated. Assuming that the photosphere is composed of nascent molecules, or molecular aggregates forming minute mist particles, this temperature is that of the complete ioniza-

* The solar envelopes include, besides gaseous material (mainly dissociated by reason of the excessive heat), the dust of the coronal filaments and some material (either molecules or mist particles) in close contact with, or perhaps in its denser distribution constituting, the photosphere. This comminuted material scatters the shorter waves powerfully.

† See the *Astrophysical Journal*, vol. xvi, p. 73 and p. 320; vol. xix, p. 139; vol. xxi, p. 1 and p. 258.

‡ The Sun, figure 25, p. 106.

§ This approximate formula requires slight modifications to adapt it to the refinements of the Wien-Planck law.

tion of solar material, and the photospheric level is determined by the depth at which this temperature is attained. Thus in low-temperature stars the photosphere may be an ill-defined misty layer of great depth, while in hotter stars the limits within which molecular structure can exist should be narrower and more sharply defined.

All observations in the solar ultra-violet spectrum show a great deficiency of energy by comparison with the theoretical curve given by the Wien-Planck law. A part of this deficiency may be due to the transference of energy, absorbed in the numerous Fraunhofer lines of the ultra-violet, to radiators of lower temperature* as already explained, but a part must be attributed to inadequate evaluation of the depletion of short waves by the terrestrial atmosphere.

The depletion of ultra-violet radiation in passing through the sun's atmosphere is of interest in another way. In this region of short waves occur the widest variations of transmissive quality in stellar atmospheres. Humphreys has suggested† that the composition of the solar atmosphere itself changes from time to time, or between maximum and minimum sun-spot epochs, sufficiently to produce a variation in the quality of the solar radiation, even though no change occurs in the total quantity of energy emitted. The known variation of the solar corona in the sun-spot period and the change in the amount of coronal dust may produce a slight alteration of transmissive quality, but by far the greater part of the change must take place in those deeply lying molecular structures in close contact with and interpenetrating the photospheric, which so greatly scatter the shorter waves and deplete them increasingly from center to limb. The thorough demonstration of this supposed change must be the subject of a lengthy research covering an entire 11-year period. Founding his hypothesis on a few observations by Abbot and Fowle, Dr. Humphreys notes that "on examining Wolfer's curves of sun-spot numbers it is seen that the days on which Abbot and Fowle found the

*For the relation between absorption and scattering in foggy media at high temperatures, see "Radiation through a Foggy Atmosphere" by Arthur Schuster (*Astrophysical Journal*, vol. xxi, p. 1, January, 1905). Were it not for scattering, "we should only obtain the continuous spectrum of the background, the medium not affecting the radiation at all" (op. cit., p. 11). Selective scattering of short waves and prominence of ultra-violet absorption lines increase with the condensation and greater internal heat of a star because mist particles, whose scattering action is more general, are fewer and only molecules remain which scatter short waves, while by the dissipation of mist the masking of the gaseous absorption by the latter ceases. This test shows that Arcturus is internally hotter than Vega (compare F. W. Very, "A Cosmic Cycle," this *Journal* (4), xiii, p. 52, March, 1902).

†W. J. Humphreys: "Solar Disturbances and Terrestrial Temperatures," *Astrophysical Journal*, vol. xxxii, p. 97, Sept. 1910.

amount of violet radiation to be relatively small were days of many spots, while the one on which they found it relatively large was a day of exceedingly few spots" (op. cit., p. 100). More extensive observations would be desirable, but the hypothesis is plausible.

If the portion of energy in the shorter waves, cut off by the scattering, be handed on to more elevated solar "dust," and again emitted as an equivalent radiation of longer wave-length from particles at a lower temperature, the solar radiation at epochs of sun-spot maxima, or whenever the coronal and other "dust" is most prevalent (as after unusual development of prominences), is richer in long waves and passes more readily through the earth's atmosphere, whence the earth's tropical regions (where the chief thermal effects are to be expected) receive a larger accession of heat at sun-spot maxima, as several meteorologists have maintained. Dr. Humphreys arrives at the opposite conclusion, and owing to the great importance which he attaches to the ozone absorption bands in the earth's atmosphere, he favors the supposition that, although more ozone may be produced in high latitudes at sun-spot maxima on account of increased electric discharges in the upper air during auroral displays, less ozone is formed in the upper air of the tropics at this time because the sun's ultra-violet rays are diminished; and on the whole the earth is then cooler, because more telluric radiation escapes in the region of the spectrum covered by the ozone bands near 10μ . My reasons for not accepting the rôle which he assigns to ozone as the most potent controller of terrestrial temperature may be seen in an article on "Sky Radiation and the Isothermal Layer."*

An increase in solar radiation does not cause higher temperatures over all the earth, but the one cause leads to opposite effects in diverse regions. An average of terrestrial thermal fluctuations may give either a positive or a negative residual according to the preponderance of stations in one or the other of the opposing classes, and the actual solar influence stands a good chance of remaining either unrecognized, or greatly underrated in climatological summaries.

In Abbot's work on "The Sun" we read: "The earth's surface air temperature is on the whole lower at sun-spot maximum than at sun-spot minimum,"† and this conclusion is reiterated on page 405: "The change of temperature of the earth seems to indicate that the sun's radiation is at a *maximum* when sun spots are *fewest*." This remark is made in connection with an allusion to the variability of Mira Ceti which "suggests the solar variability associated with sun-spots," but which is here

* This Journal (4), vol. xxxv, pp. 369-388, April, 1913.

† P. 190.

supposed to exhibit a law of change opposite to that of the sun: "Mira increases in brightness faster than it decreases." The discrepancy, however, arises from what I believe to be a mistaken conclusion in regard to the variation of terrestrial temperatures attributable to solar changes. In my paper on "The Variation of Solar Radiation," I concluded that "the maximum temperatures are higher for a time of many sun-spots in the torrid zone, and lower in the temperate zone."* The cause of hesitation in the acceptance of this conclusion is also pointed out: "Most of our material comes from the temperate zones and is difficult to analyze. The fact that so large a part of the earth is in lower latitudes than the average storm-belts, and that the greater part of this surface is oceanic, warns us that our mid-latitude storms are a mere fringe on the grander field of tropical atmospheric activities."† "It does not appear to be necessary that the sign of such temperate residual should agree with that from the tropics. While higher tropical temperature produced by greater solar radiation must increase convection, which may transfer extra heat to the temperate and polar zones, it is quite possible that certain regions may get more than their share of the returning polar winds concerned in the convection, and may have their temperature lowered thereby. This, in fact, appears to be the case in the upper Mississippi valley and in Europe."‡

The prevalent scientific opinion that the earth is cooler at sun-spot maximum is, I believe, contrary to fact, and has apparently arisen because most of the people who hold this opinion reside in the region of "the returning polar winds concerned in the convection." Mr. Henry F. Blanford, than whom there has been no more competent student of the meteorology of the torrid zone, says in his "Indian Meteorologists' Vade-mecum"§ that "the solar radiation is greatest in years of abundant sun-spots and *vice versa*. . . . The results of eleven stations, in different parts of India, showed an increase of at least 6° in the mean equilibrium temperature of solar radiation at the earth's surface between 1868 and 1871 (the last following a year of maximum sun-spots); and this, I am inclined to think, is in defect of the truth. The variation is thus by no means inconsiderable."

In explanation of the discrepancy between his results and those of Köppen, Blanford says: "The temperatures dealt with by Professor Köppen are, of course, those of the lowest stratum of the atmosphere as observed at land stations, and must be determined, not by the quantity of heat that falls on

* Astrophysical Journal, vol. vii, p. 255, April, 1898.

† Op. cit., p. 263.

‡ Op. cit., p. 264-5.

§ P. 159.

the exterior of the planet, but on that which penetrates to the earth's surface, chiefly the land surface of the globe. The greater part of the earth's surface being, however, one of water, the principal immediate effect of the increased heat must be to increase the evaporation, and therefore, as a subsequent process, the cloud and the rainfall. Now a cloudy atmosphere intercepts a great part of the solar heat; and the re-evaporation of the fallen rain lowers the temperature of the surface from which it evaporates, and that of the stratum of air in contact with it. The heat liberated by cloud condensation doubtless raises the temperature of the air at the altitude of the cloudy stratum, but this is not recorded in our registers. As a consequence, an increased formation of vapor, and therefore of rain, following on an increase of radiation, might be expected to coincide with a low air-temperature on the surface of the land."* This explanation does not exclude the one which I have suggested, but is to be looked upon as an additional cause of local discrepancies which do not invalidate the wider conception which includes them. Mr. Blanford refers to his explanation as a "speculation . . . in part suggested by the discovery of Messrs. Meldrum and Lockyer that the frequency and energy of cyclones and the rainfall of the globe appear to vary directly as the abundance of sun-spots."

It will be seen that in this case, as in some others, Mr. Abbot has included only one side of a controverted subject in his treatise. In more than one place he also cites as authorities for his statements names of investigators who have held diverse opinions. Mention is made† of the shifting of the zones of maximum frequency of prominences, but no notice is taken of the short period of this shift (3 to 4 years) which is shown by Lockyer's curves for solar latitudes 30° to 60° . Bigelow finds that this shift synchronizes with a periodic change in terrestrial climates which is even more marked than the 11-year cycle. He says: "The frequency variation of the solar prominences in the higher latitudes gives the key that was wanted to enable us to study the meteorological conditions in the earth's atmosphere with some prospect of success. This variation shows that the meteorological pulse is registered most favorably not in the sun-spot belts, but in the zones of the sun corresponding with the temperate zones of the earth from latitude 30° to 60° ."‡

Owing to the periodic interchange of climatic conditions over extensive areas of the earth's surface, we have the phe-

* *Astrophysical Journal*, vol. vii, p. 159-160.

† *The Sun*, p. 195.

‡ Frank H. Bigelow: "Studies on the Diurnal Periods in the Lower Strata of the Atmosphere," p. 41. U. S. Weather Bureau, 1905.

nomenon of "inversion"* discovered by Bigelow, which complicates the meteorological problem still more. Into this problem enter: (a) the solar constant whose estimation can not be made without hypotheses, and whose variation remains uncertain; (b) changes in the solar spectrum which synchronize with the sun-spot cycle and show an alteration in at least the *quality* of the solar radiation; (c) variations in the solar corona in the 11-year period, which may affect the earth by a solar emission of kathode rays or by some other process different from the ordinary radiation; (d) climatic cycles which are of opposite nature in different parts of the earth and of several periods (including the 11-year period). No climatic theory can be considered complete which does not consistently harmonize these details.

Many attempts have been made to derive formulas connecting the absorption of solar radiation with the aqueous vapor of the atmosphere, but with such small success that the effort has been generally abandoned. Nevertheless, the total omission of a vapor factor in the computation of the solar constant must be remedied, for it is certain that atmospheric moisture has a depleting action on the incoming as well as on the outgoing radiation. This may be known because (1) the form of the diurnal curve of solar radiation changes from a symmetrical shape with relative freedom from fluctuations in cold, dry winter weather, to a flattened and unsymmetrical shape beset with sinuosities in summer. (2) The total solar radiation through identical masses of air is smaller in moist, summer weather than in cold and dry winter weather, and this diminution of intensity in summer is associated not only with increase of the aqueous absorption-bands in the infra-red spectrum, but with an increased depletion of the shorter waves of the visible and ultra-violet parts of the spectrum. (3) As a result of the last-named depletion, red sunsets are characteristic of the tropics and summer, or of the approach of hot waves and increased atmospheric moisture, while the fading of the dawn and sunset tints implies a widely prevalent dryness in the atmosphere, associated with cold because the terrestrial radiation also escapes through the atmosphere more freely at such times. (4) If we compare the solar radiation *with equal air masses* we shall find that (a) in the morning and afternoon of the same day, the afternoon measurement will usually be the smaller because, in general, evaporation of surface moisture has increased the vapor content of the air in the afternoon, and (b) that of simultaneous measures at different altitudes on a

* Inversion of temperature consists not merely in a general synchronous opposition of thermal changes in different parts of the earth, but includes minor details in the distribution and amplitude of the thermal fluctuations.

mountain, the more elevated and drier station gives the larger radiation. The effect here is complicated by a dust-factor, but it can not be doubted that water vapor has some part to play in this variation of atmospheric quality.

FIG. 1.

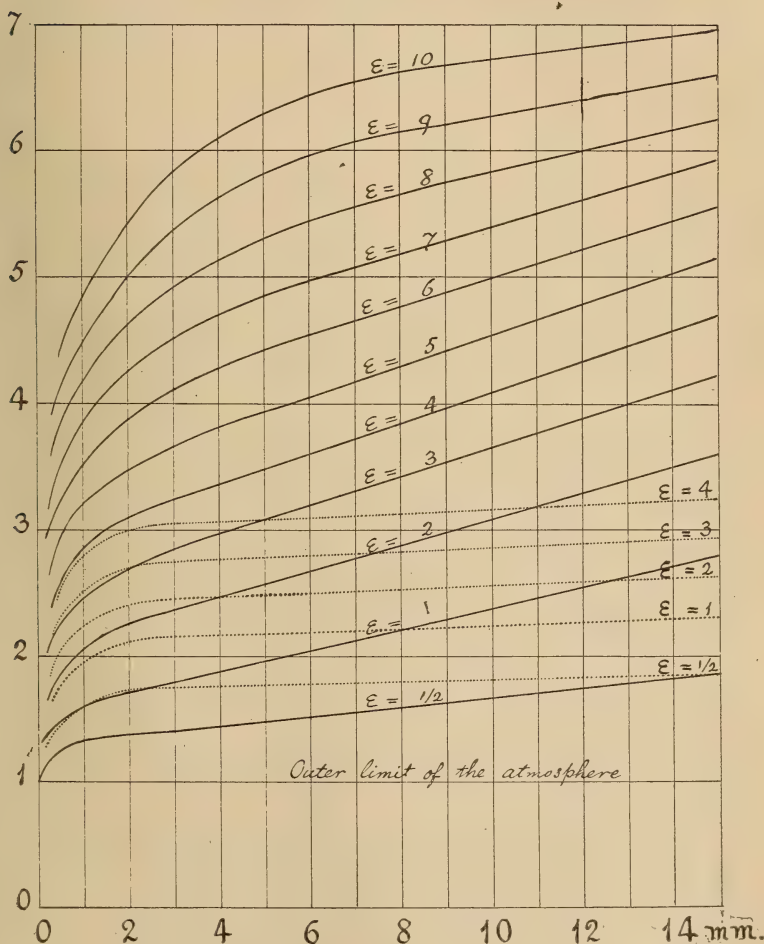


FIG. 1. Abscissæ = pressure of aqueous vapor in the free air at the level of the place of observation. Ordinates = factors for reducing observed solar radiation to corresponding values at the outer limit of the atmosphere. Full lines are for sea-level. Dotted lines are for level of Mt. Wilson = 1780 meters. $\epsilon = (B/B_0) \times \text{Sec. } \zeta$.

The actinometric method of solar investigation is not capable of yielding exact values of the solar constant except under rare

combinations of atmospheric conditions,* but since actinometric observations are easily made and have been accumulated in great numbers for many years, it is desirable to see whether some use, even though an imperfect one, may be made of this material, and especially whether a way may be found to eliminate the depleting action of aqueous vapor. The chart (fig. 1) has been constructed from the numbers in the following table.†

Air-masses $\varepsilon =$	$\frac{1}{2}$	1	2	3	4	5	6	7	8	9	10	Pressure of aqueous vapor.
Radiation (gr. calories per sq. cm. per min.)	2.66	2.22	1.73	1.46	1.26	1.12	1.02	0.94	0.87	0.81	0.76	mm. 0.8
	2.40	1.88	1.36	1.13	1.01	0.89	0.79	0.72	0.66	0.59	0.53	5.0
	1.86	1.22	0.97	0.83	0.73	0.68	0.63	0.59	0.55	0.51	0.47	15.0
Factors reduc- ing to Solar constant.	1.316	1.58	2.01	2.40	2.78	3.13	3.43	3.72	4.02	4.32	4.61	0.8
	1.46	1.84	2.57	3.05	3.47	3.93	4.43	4.86	5.30	5.85	6.42	5.0
	1.88	2.82	3.61	4.22	4.70	5.15	5.56	5.93	6.36	6.60	6.95	15.0

By the aid of this chart actinometric measures may be corrected for atmospheric absorption in a somewhat rude but fairly satisfactory manner, provided a sufficient body of data exists for the elimination of fluctuations in a final mean value. The method requires, in addition to the actinometric readings, simultaneous observations of the atmospheric aqueous vapor. By rights these should include the distribution of aqueous vapor through a considerable part of the air column, which can be obtained only by the meteorological records of high kite-flights, or of sounding balloons. In the absence of vapor records for the upper air, wide fluctuations in the computed solar constant must inevitably be found, because the pressure of aqueous vapor at the earth's surface is only imperfectly related to the quantity of precipitable and absorbent vapor in the entire air-column.

As an example of the results to be expected from this chart, I take at random from volume 2 of the *Annals of the Smithsonian Astrophysical Observatory*, the actinometric observations of five days at Washington, merely looking out to get a considerable range in the pressure of aqueous vapor so as to test the method. The recorded data are insufficient for more than rough approximations. Only one, or at most two vapor readings (Aq.) are given on each day. In these examples,

* For which see "A Criterion of Accuracy in Measurements of Atmospheric Transmission of Solar Radiation," *Astrophysical Journal*, vol. xxxvii, p. 31, January, 1913.

† Read from fig. 4 of my "Criterion" paper just cited, and checked by numerous examples.

ζ = sun's zenith distance. No barometric pressures are published. Consequently, I assume that the air pressure was normal and take air masses, $\epsilon = \sec. \zeta$. Radiation is denoted by R, and the factor F is read by inspection from the chart with ϵ and Aq as arguments, giving as many estimates of the solar constant, $A = FR$, as there are readings.

	Sec. ζ .	R.	F.	A.
August 24, 1903 Aq.=14.66 ^{mm} .	1.148	1.092	2.90	3.167
	1.188	1.107	2.94	3.255
	1.242	1.074	2.98	3.201
	1.466	1.013	3.15	3.191
	(4 obs.)			Mean=3.204
	Reduced to sun's mean distance			3.255
December 23, 1903 Aq.=3.30 ^{mm} .	2.158	1.160	2.47	2.865
	2.150	1.121	2.47	2.769
	2.150	1.060	2.47	2.618
	2.248	1.155	2.51	2.899
	2.266	1.175	2.52	2.961
	2.360	1.151	2.57	2.958
	2.390	1.103	2.59	2.857
	2.520	1.096	2.66	2.915
	2.552	1.099	2.69	2.956
	2.979	1.017	2.86	2.909
	3.113	1.008	2.93	2.953
	(11 obs.)			Mean=2.878
	Reduced to sun's mean distance			2.770
May 28, 1904 Aq.=6.50 ^{mm} .	1.100	1.351	2.15	2.905
	1.107	1.347	2.16	2.910
	1.142	1.287	2.18	2.806
	1.150	1.295	2.18	2.823
	1.200	1.311	2.22	2.910
	1.212	1.299	2.23	2.897
	1.282	1.216	2.27	2.760
	1.297	1.135	2.29	2.599
	1.390	1.225	2.35	2.879
	1.410	1.220	2.36	2.879
	1.572	1.180	2.46	2.903
	1.600	1.175	2.48	2.914
	1.843	1.078	2.64	2.846
	1.888	1.103	2.66	2.934
	(14 obs.)			Mean=2.855
	Reduced to sun's mean distance			2.920

	Sec. ζ.	R.	F.	A.
October 21, 1904 Aq. = 7.29 ^{mm} .	1.568	1.533	2.53	3.878
	1.580	1.406	2.54	3.571
	1.587	1.384	2.54	3.515
	1.594	1.394	2.54	3.541
	1.653	1.424	2.58	3.674
	1.666	1.384	2.59	3.585
	1.680	1.435	2.60	3.731
	1.820	1.304	2.69	3.508
	1.844	1.354	2.70	3.656
	1.870	1.394	2.72	3.791
	2.172	1.321	2.89	3.818
	2.214	1.260	2.91	3.667
	2.682	1.253	3.17	3.972
	2.760	1.209	3.21	3.881
	2.845	1.158	3.26	3.775
	3.845	0.999	3.69	3.686
	4.030	0.953	3.77	3.593
	(17 obs.)			Mean = 3.697
	Reduced to sun's mean distance			3.639
January 9, 1906 Aq. = 1.96 ^{mm} .	2.149	1.360	2.32	3.155
	2.163	1.365	2.33	3.180
	2.179	1.344	2.34	3.145
	2.279	1.365	2.39	3.262
	2.300	1.365	2.40	3.276
	2.326	1.367	2.41	3.294
	2.500	1.337	2.49	3.329
	2.540	1.318	2.51	3.308
	2.580	1.304	2.53	3.299
	3.080	1.194	2.74	3.271
	3.163	1.171	2.77	3.244
	3.246	1.147	2.81	3.223
	3.740	1.036	2.99	3.098
	3.870	1.021	3.03	3.094
	(14 obs.)			Mean = 3.227
	Reduced to sun's mean distance			3.106

Although the observations of a given date are in tolerably good accord, considerable discrepancy is found between the mean results for days of nearly the same vapor pressure, such as May 28 and October 21, 1904. But, on the other hand, days in which the aqueous vapor at the surface has varied in the ratio of 1.0 : 7.5 (August 24, 1903, and January 9, 1906) yield almost identical results by the reduction, showing that the method is competent to harmonize a wide range of sum-

Aqueous vapor between 1.5^{mm} and 4.5^{mm}, or about 3^{mm}.

	Date.	No. of Obs.	Aq. mm.	ϵ from	to	Mean A.	At mean solar distance.
1905	June 6	24	1.91	2.17	0.83	2.774	2.845
	" 14	28	2.30	3.25	0.83	3.023	3.106
	" 20	12	3.96	1.86	0.90	2.989	3.073
	" 23	16	4.31	2.88	0.85	3.335	3.430
	July 19	14	2.68	2.08	0.93	2.922	3.002
1906	" 21	16	4.28	2.08	0.86	3.127	3.210
	Oct. 26	10	3.38	2.64	1.27	3.333	3.280
	May 17	16	4.19	2.17	0.84	2.994	3.053
	" 29	17	3.74	3.03	0.97	3.312	3.389
	" 30	17	4.46	3.19	0.88	3.298	3.376
	June 7	20	4.12	3.08	0.89	3.310	3.395
	" 29	16	4.30	2.67	0.89	3.238	3.331
	Aug. 8	18	4.48	2.63	0.86	3.279	3.352
	" 21	18	4.33	3.67	0.95	3.104	3.157
	" 23	16	3.81	3.13	0.93	3.472	3.529
	" 25	16	4.34	3.21	0.95	3.329	3.381
	Sept. 18	12	3.43	3.08	0.97	3.204	3.214
	Oct. 4	13	2.47	3.86	1.08	3.069	3.051
	" 6	12	2.44	3.09	1.06	3.887	3.859
	" 9	14	2.57	3.10	1.08	3.151	3.123
	" 11	14	2.97	3.29	1.09	3.148	3.116
	" 13	12	2.18	3.32	1.14	3.070	3.036
	" 16	12	2.91	3.62	1.15	3.410	3.366
	" 18	11	3.76	3.90	1.13	3.339	3.293
	" 20	10	1.59	3.50	1.26	3.245	3.196
	" 23	18	1.92	4.47	1.18	3.287	3.232
	Mean	Aq.=	3.340		Mean	A=	3.246

mer and winter readings, and that the remaining discrepancies arise from the inadequacy of the surface vapor pressure as an indicator of total moisture. The chart is also imperfect because the absorption of radiation by water vapor varies with the relative humidity as well as with the vapor pressure, while only the latter is considered here. To illustrate the great disadvantage under which we labor in estimating the effect of aqueous vapor upon radiation, it is only necessary to point out that a layer of air approaching saturation, but not yet visibly cloudy, may occur at various altitudes, and that sometimes several such layers are found in succession in balloon ascents. But the absorption by water vapor is strongly enhanced near the condensation point, and the unknown possibilities of the

upper air in this respect are sometimes great enough to upset all calculations.

In attempting to use the chart (founded on observations at or near sea level) in the reduction of the Mt. Wilson measurements of solar radiation in the same volume of the *Annals*,* it was evident that different curves are required. Having no observations suitable for the construction of a new chart of the same extent as fig. 1 and adapted to mountain conditions, I first employed the present chart (full lines) to get a preliminary reduction. The vapor readings on the mountain are multiplied by 0.887, according to Hann's prescription, to get the vapor in

Aqueous vapor between 4.5^{mm} and 7.5^{mm}, or about 6^{mm}.

	Date.	No. of Obs.	Aq. mm.	ϵ from	to	Mean A.	At mean solar distance.
1905	June 7	14	7.17	3.59	0.83	3.614	3.707
	" 13	14	5.36	1.96	0.90	3.369	3.460
	" 26	12	5.83	1.72	0.97	3.373	3.469
	" 28	14	5.63	2.32	0.84	3.426	3.524
	July 6	12	5.14	1.77	0.99	3.262	3.356
	" 11	12	5.67	1.76	0.89	3.239	3.332
	" 12	14	6.66	2.70	0.88	3.449	3.546
	" 22	8	7.42	3.58	1.72	4.112	4.223
	" 25	27	{ 7.61 5.53 }	2.27	0.84	3.237	3.322
	" 28	16	6.02	2.33	0.89	3.366	3.452
	" 31	18	4.64	2.51	0.92	3.376	3.459
	Aug. 3	17	5.63	2.33	0.92	3.428	3.510
	" 29	12	6.63	3.42	1.08	3.504	3.551
	Sept. 5	12	5.38	3.13	1.03	3.306	3.339
	" 8	28	{ 8.13 4.62 }	2.80	0.93	3.280	3.308
	" 11	12	6.06	3.07	1.12	3.518	3.542
	" 13	10	6.06	2.65	1.16	3.364	3.384
	" 14	12	5.74	2.38	0.95	3.353	3.370
	" 15	12	4.76	3.29	1.08	3.528	3.545
	" 27	24	5.65	2.90	1.00	3.608	3.600
1906	Oct. 24	12	5.69	2.93	1.17	3.634	3.572
	May 18	11	6.60	2.11	0.98	3.362	3.428
	" 19	14	4.84	1.87	0.86	3.140	3.202
	June 6	20	4.68	3.12	0.90	3.260	3.345
	" 9	22	5.77	3.04	0.85	3.317	3.404
	" 15	24	7.46	2.63	0.83	3.558	3.656
	Mean	Aq. =	5.942		Mean	A =	3.485

* Op. cit., Table 13, pages 87 to 92.

Aqueous vapor between 4.5^{mm} and 7.5^{mm}, or about 6^{mm}.

	Date.	No. of Obs.	Aq. mm.	ϵ from	to	Mean A.	At mean solar distance.
1906	June 16	20	6.40	2.96	0.89	3.415	3.510
	" 19	23	5.68	2.99	0.83	3.251	3.342
	" 20	16	5.79	2.00	0.84	3.377	3.471
	" 22	16	5.81	2.10	0.83	3.399	3.494
	" 23	16	5.79	2.40	0.92	3.358	3.453
	" 30	16	5.72	2.56	0.89	3.348	3.444
	July 3	14	7.46	2.37	0.89	3.415	3.514
	" 18	14	7.18	2.66	0.93	3.495	3.591
	" 28	16	7.08	2.60	0.91	3.480	3.570
	" 31	16	6.92	2.65	0.87	3.716	3.808
	Aug. 1	14	5.22	2.70	0.92	3.550	3.637
	" 3	16	4.58	2.92	0.90	3.343	3.423
	" 4	16	6.24	2.67	0.93	3.516	3.599
	" 7	16	5.17	2.38	0.86	3.337	3.413
	" 15	12	6.92	2.73	1.10	3.306	3.371
	" 29	8	6.03	2.32	1.17	3.008	3.049
	" 31	20	6.61	2.76	0.90	3.252	3.294
	Sept. 1	15	5.18	2.48	0.91	3.296	3.336
	" 4	7	4.52	3.09	1.00	3.393	3.430
	" 5	16	5.02	3.01	0.93	3.361	3.394
	" 11	12	4.68	2.95	0.94	3.426	3.449
	" 20	12	4.71	3.22	0.98	3.208	3.214
	" 25	12	4.72	3.06	1.01	3.268	3.265
	" 28	14	5.14	3.60	1.00	3.336	3.328
	Oct. 2	11	5.81	2.79	1.03	3.354	3.337
	Mean	Aq.=	5.775		Mean	A=	3.430

the free air. No readings of the barometer are available, and I am therefore obliged to assume an average pressure for the mountain, which is taken = 618^{mm}. Accordingly the air mass is made = $(618/760) \times \sec. \zeta = 0.813 \sec. \zeta$. The results are given in the tables on pp. 623–626, grouped approximately for aqueous vapor pressures of 3, 6 and 9^{mm}.

The mean values, with two others which fall outside the limits of the classification, are plotted in fig. 2.

Aqueous vapor=3.340

" " 5.775

" " 5.942

" " 8.861

" " 12.44

" " 13.84

A=3.246 (26 observations).

3.430 (25 ").

3.485 (26 ").

3.744 (23 ").

4.391 (1 ").

4.489 (1 ").

Aqueous vapor between 7.5mm and 10.5mm, or about 9mm.

	Date.	No. of Obs.	Aq. mm.	ε from	to	Mean A.	At mean solar distance.
1905	June 17	20	10.07	2.44	0.83	3.871	3.978
	Aug. 14	14	9.92	2.83	1.00	4.017	4.099
	" 18	12	7.51	2.35	0.99	3.476	3.540
	" 21	12	9.88	2.24	1.00	3.655	3.718
	" 24	13	7.64	3.24	1.01	3.503	3.558
	" 25	27	{ 10.49 }	4.02	0.89	3.850	3.909
			{ 10.24 }				
	" 30	29	{ 10.48 }	4.55	0.94	3.740	3.788
			{ 7.81 }				
	Sept. 19	20	9.64	2.53	0.97	3.865	3.876
	" 21	16	7.85	2.82	0.97	3.668	3.673
	" 26	10	7.57	2.17	1.01	3.608	3.603
	Oct. 3	10	8.98	2.38	1.04	3.900	3.879
1906	June 12	28	10.02	2.98	0.88	3.918	4.024
	July 6	16	8.69	2.72	0.87	3.496	3.596
	" 10	20	8.50	2.52	0.88	3.365	3.461
	" 11	16	7.71	2.67	0.89	3.290	3.384
	" 17	16	6.67	3.15	0.94	3.501	3.598
	" 21	12	8.54	2.47	0.94	3.414	3.505
	" 24	8	10.02	2.74	1.34	3.561	3.656
	" 27	18	7.86	2.53	0.94	3.537	3.628
	Aug. 14	15	8.51	2.65	0.92	3.522	3.593
	" 17	8	9.50	2.73	1.35	3.741	3.812
	Sept. 8	6	9.11	3.12	2.11	4.209	4.245
	" 9	16	8.31	3.83	0.93	3.950	3.982
	Mean	Aq. =	8.861		Mean	A =	3.744

The values of A obtained by the first chart increase with the aqueous vapor. They should be constant, and fig. 2 has been used to give a corrected chart, shown by the dotted lines in fig. 1, with the following multiplying factors appropriate to conditions on the mountain :

Air-Mass.	Aq. = 1.5mm.	Aq. = 3mm.	Aq. = 6mm.	Aq. = 9mm.	Aq. = 15mm.
4	2.90	3.05	3.15	3.20	3.25
3	2.64	2.75	2.85	2.90	2.95
2	2.35	2.45	2.53	2.57	2.63
1	2.05	2.15	2.20	2.25	2.30
0.5	1.70	1.75	1.77	1.80	1.85

The following examples are taken at random to show that the observations are satisfied by the factors read from the dotted lines of the chart :

Mt. Wilson.	ϵ	R	F	A	Mt. Wilson.	ϵ	R	F	A
Oct. 20, 1906.	3.496	1.336	2.79	3.727	June 7, 1905	3.59	1.185	3.05	3.614
	3.285	1.358	2.73	3.707		3.40	1.217	2.98	3.627
Aq.=1.59 ^{mm} .	1.832	1.565	2.31	3.615	Aq.=7.17 ^{mm} .	2.872	1.345	2.66	3.578
	1.791	1.558	2.30	3.583		2.280	1.357	2.64	3.582
	1.555	1.596	2.24	3.575		1.786	1.433	2.48	3.554
Morning	1.528	1.634	2.23	3.644	Morning	1.734	1.444	2.47	3.567
measures.	1.380	1.628	2.18	3.549	measures.	1.120	1.579	2.27	3.584
	1.363	1.636	2.17	3.550		1.110	1.604	2.26	3.625
	1.276	1.652	2.15	3.552		1.006	1.611	2.23	3.593
	1.263	1.642	2.14	3.514		0.993	1.620	2.21	3.580
						0.871	1.643	2.13	3.500
						0.871	1.675	2.13	3.568
						0.832	1.604	2.09	3.352
						0.831	1.561	2.09	3.262
Mean 3.602					Mean 3.542				
At sun's mean distance, A=3.547					At sun's mean distance, A=3.634				

Mt. Wilson, Aug. 22, 1905, a. m. and p. m. Aq.=13.84^{mm}.

ϵ	R	F	A	ϵ	R	F	A
3.104	1.229	2.97	3.650	1.122	1.497	2.33	3.488
2.967	1.242	2.92	3.627	1.138	1.458	2.34	3.412
2.254	1.327	2.71	3.596	1.244	1.476	2.37	3.498
2.176	1.348	2.68	3.613	1.265	1.481	2.37	3.510
1.281	1.506	2.38	3.584	1.419	1.437	2.43	3.492
1.261	1.497	2.37	3.548	1.447	1.449	2.44	3.536
1.124	1.520	2.33	3.542	1.676	1.403	2.52	3.536
1.110	1.531	2.32	3.552	1.722	1.391	2.54	3.533
1.023	1.510	2.29	3.458	2.053	1.325	2.63	3.485
1.015	1.547	2.29	3.543	2.126	1.332	2.66	3.543
0.879	1.568	2.18	3.418	Mean 3.526			
0.878	1.559	2.18	3.399	At sun's mean distance			
				A=3.585			

The factor-curves (dotted lines, fig. 1) for the mountains are somewhat more square-shouldered than those for sea-level, and the factors to be used on the mountain for the larger air masses and vapor pressures are smaller. Apparently the mountain curves for values of e greater than 4 are more closely crowded together, although there are not enough low sun observations to assign the law. Scarcely any effect is produced

on the mountain by variations of aqueous vapor pressure between $1\frac{1}{2}$ and 15^{mm} . Consequently, the aqueous absorption has already produced very nearly its maximum effect in the upper region of the isothermal layer, and the water vapor near the level of the mountain top is not in a condition to produce much new depletion.

FIG. 2.

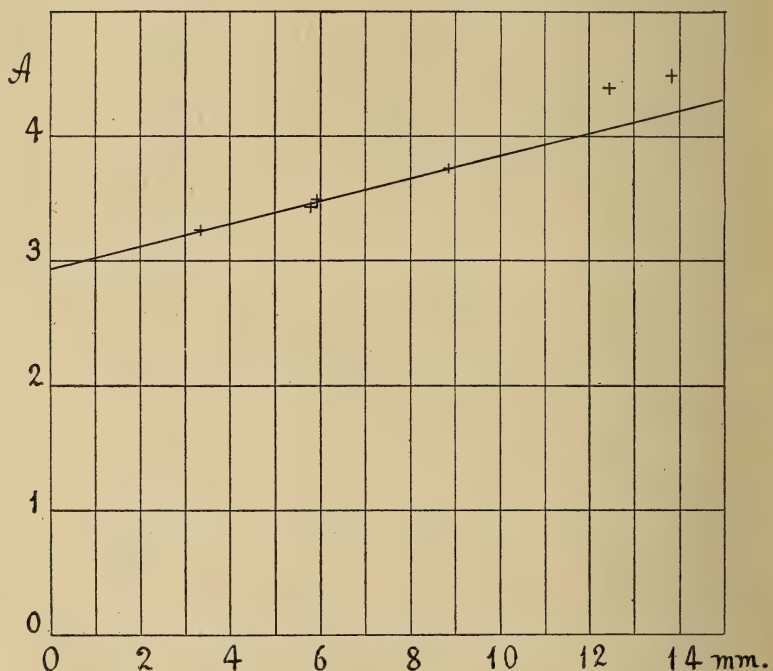


FIG. 2. Abscissæ = pressure of aqueous vapor. Ordinates = values of A by preliminary chart.

The case is different at sea-level, where a much more prominent vapor factor is required. The vapor of the lower air, by its condensation-products on the dust particles out of which the haze which gives to distant hills and mountains their blue tint takes its birth, has added a new sort of depletion in the lower air layers which is very much less effective in the purer air above the mountain top (altitude = 1780 meters). The average values of A in the examples given here are:

Washington (5 days), $A = 3.138 \pm .105$.

Mt. Wilson (3 days), $A = 3.589 \pm .017$.

The result is still affected by any uncompensated depletions in addition to those considered. Thus the lower value of A from the sea-level measurement is caused by the greater infringement of dust in the lower air.

That lower values of solar radiation are obtained at low-level stations when compared with mountain observations for identical air-masses was recognized by Langley, who found when he computed by the inadequate secant formula, from valley observations at Lone Pine, California, the radiation which might be expected at his "Mountain Camp" on Mt. Whitney, and compared this with the observed value, the latter exceeded the calculated amount. The reason for this may be evident from the following considerations: The exponent of

FIG. 3.

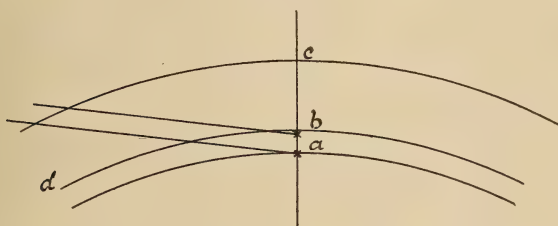


FIG. 3. a and b = observing stations. c = outer limit of air. d = upper limit of dust envelope.

the dust-coefficient does not vary according to the total air mass. At a certain altitude, in itself variable, the dust disappears and the term representing the dust effect must drop out from the complete formula. The condition as to dust is shown in fig. 3, where the more elevated of two stations, a and b , experiences but a small fraction of the depletion of radiation by dust which affects the lower station, although the air masses are not very different.

In my paper on "The Solar Constant,"* I have treated the dust depletion separately and have used a modified air mass (ϵ') computed by Lambert's formula† where it is necessary to eval-

* U. S. Weather Bureau Publication, No. 254, 1901.

† The word "kilometer" (op. cit., p. 14, l. 1) should be erased. The five is an approximate numerical ratio, and not a distance, as may be seen from the derivation of the formula, for which consult Ferrel, "Recent Advances in Meteorology," Appendix 71, p. 61. Annual Report of the Chief Signal Officer, 1885, War Department, U. S. A. There are two other typographical errors in W. B. No. 254: The expression for p on p. 18 should have the exponent m , and "log" should precede w in equation (a) p. 27. In the footnote to my "Note on Atmospheric Radiation," this Journal for April, 1913 (p. 536), the exponent of 10 should be -8 , instead of -4 , and the black-body radiations should be 371.1 and 136.3 (M. K. S.), the values in small calories remaining unchanged. The same error in the exponent occurs in Bigelow's paper in the March number of the Journal, p. 258, l. 9 from bottom.

uate the air mass of the dust layer. No satisfactory mode of estimating the dust factor has yet been devised, and the suggested separation of the dust depletion from the air depletion, though theoretically necessary and much to be desired, is not yet on a practicable basis. Mr. Abbot* characterizes the method as arbitrary, a criticism which is partially justified since, unfortunately, the data for a reliable estimate of the amount of dust in the air, and the depletion which it exercises, are both regrettably deficient; but to ignore the dust factor entirely and to omit even an imperfect discrimination of this important variable is equally arbitrary. One great merit of winter observations in high continental latitudes is the reduction of atmospheric dust to a minimum over extensive snow fields, and for this reason such measures are the best we have for determining the solar constant.† The sole justification for the total omission of any dust factor in the present reduction is the absence of observations on which even an approximate estimate of its amount may be founded. Increasing pressure of water vapor is apt to be accompanied by a growing mistiness of the air, which is of the nature of a dry fog and implies an increment of the action of presumably pre-existing dust particles of excessive fineness which are enlarged and become evident when serving as nuclei of condensation. This is probably the reason why the dust depletion may be represented to a certain extent as a function of the vapor pressure, which is tacitly done when only the latter is considered, as in the present examples.

The value of about $3\frac{1}{2}$ cal./sq. cm. min. which is given by the mean of the reduced Mt. Wilson observations must not be taken as an independent determination of the solar constant. Other and better methods must be employed to get a reliable value of this quantity. The sole merits of the present reduction are that it permits the approximate utilization of measures which would be of no value without some mode of supplying the lost radiation, and that it justifies the assumption that the radiant depletion is most intimately connected with the amount of aqueous vapor in the atmosphere.

In spite of imperfections, the considerable number of observations averaged justifies some general conclusions. The use of the chart very nearly corrects for the direct effect of water vapor and for some of its indirect influence, although the curves might be improved by data from tropical regions of large vapor-content. The very marked midday depression of solar radiation, which results from the diurnal change in atmospheric transmissive quality and which increases with the amount of aqueous

* *Annals Smithsonian Observatory*, vol. ii, p. 119.

† Compare my "Criterion of Accuracy," etc., already cited, and especially the notable work by Savélieff, which is there described.

vapor in the air, ought to appear in the separate values of A for a given date, since no attempt has been made to eliminate the diurnal change of quality, and the depression does appear in the Mt. Wilson reductions; but there is little evidence of this feature in the reductions for Washington, D. C., whence we must conclude that the ordinates of the sea-level curves, $\epsilon = 1$ and $\epsilon = 2$ (full lines), which are most used in the midday reductions, are relatively a little too high (i.e. the curves for $\epsilon = 3$ and 4 should be raised a little), and that the chart automatically, but unintentionally and indirectly, obliterates the depression to a great extent at sea level. By comparing numerous radiation measures for vapor pressures ranging between 5 and 15^{mm}, midday radiations of solar radiations covering 0.2 cal. in thermal equivalent may be found, but the most potent influence of aqueous vapor does not begin to appear until vapor pressures much less than 1^{mm} are reached.

The need of rational methods and of judicious selection of material according to reliable criteria was never more pressing than in the reduction of observations of solar radiation. The treatment of climatic problems involving radiant functions has been vitiated by indiscriminate averaging of statistic in which delicate details, whose preservation is important, have been swamped. Professor Simon Newcomb, in an elaborate memoir of seventy-nine quarto pages, "A Search for Fluctuations in the Sun's Thermal Radiation through their Influence on Terrestrial Temperature,"* arrived at the result that no solar radiant variations of sensible amount can be recognized by their effect on climate. He concluded that "all the ordinary phenomena of temperature, rainfall and winds are due to purely terrestrial causes and that no changes occur in the sun's radiation which have any influence upon them" (p. 384).

The fundamental principles assumed in Newcomb's work may be seen from the following quotations: "A change in the sun's radiation will necessarily affect every part of the earth. If therefore a change of temperature in one region has this cause as a factor, we may, accidental causes aside, expect a similar change in every other region. . . . To speak more precisely, if, on any one day, it is found that the temperature in every part of the earth is in the general average above or below the normal, we might rationally attribute this result to the sun. We thus see that a very obvious way of testing the constancy of the solar radiation is to determine the deviation of the

* Transactions of the American Philosophical Society, N.S., vol. xxi, Part 5, pp. 309-387, 1908. The distinction of "thermal" radiation is superfluous, since all radiation is capable of producing thermal effects. The word was not introduced in the obsolete sense of "infra-red," but to distinguish ordinary radiation from possible "magnetic or radio-active emanations, whatever they may be" (p. 382).

temperature from the normal on any one day over all points of the globe, and form their mean. The fluctuations of this mean would represent those of the sun's radiation" (p. 314). Of two regions, A and B, "if we found that the mean temperature at B was above normal when it was above the normal in A, and below it in the contrary case, it would show that there was some common cause affecting the two places. Should the mean temperature in B be entirely independent of A it would show that there was no common cause affecting the temperature of the two places and therefore that the fluctuations were not due to changes in the sun's radiation" (p. 315).

These are extraordinary principles to adopt as the basis for discovering changes in the solar radiation. One might as reasonably anticipate a simultaneous high tide over all the earth as to "expect a similar change in every other region" if a particular climatic effect in some one region is attributable to a variation in solar radiation. Climatic phenomena are seldom regulated in such a simple and direct way, but a given change in one part of the earth, even if caused by an increase or decrease of solar radiation, will set in action a long train of consequences and will be accompanied by an opposite change somewhere else, while between the localities of opposing effects lie apparently neutral belts of conflicting phases.

In comparing solar effects for different localities we must first be sure that the phases are the same, otherwise the signs should be changed for the region of inverted type. Next we must recognize that, while types may persist over extensive areas of the earth's surface, there are intermediate regions in which the type varies through shifting of the great centers of action which govern world-wide circulatory phenomena of the atmosphere. Any lag in the phase will require a time-adjustment before the waves for different locations can be compared. Finally, it is probably a mistake to assume that the solar radiant changes can be represented by a simple sinusoid curve, as though they were regular like the planetary revolutions. On the contrary, the solar changes are only approximately periodic, and several different periods, each of slightly varying duration, are superposed. Even harmonic analysis, which deals successfully with simultaneous sinusoid phases of various periods, is nonplussed by such a complex.

Newcomb's rigid criterion starts with an erroneous hypothesis. The criterion has been invented to get rid of the accidental fluctuations, which it does, but at the same time it also eliminates the solar radiant phases which it is proposed to investigate. No other outcome than a purely negative one was to be anticipated. It was principally to meet the special case of a periodicity of varying length that Newcomb devised his "criterion for distinguishing between a definite period

[even though this be of fluctuating length] and complete irregularity," always, however, subject to the supposition that there is no question in regard to the identification of maximum and minimum in the phase, but that the maxima, or positive departures in surface temperature due to variation of solar radiation, will everywhere coincide. This is the fundamental error which overthrows the final conclusion. There may be provision for detecting a slight lag, but there is none for dealing with a complete reversal of phase. If, however, instead of attempting to apply his criterion to the whole world, Newcomb had tried it on a single homogeneous region of one common type, he would not have cancelled out his opposing phases. Bigelow* has used the method for a particular region where the solar radiant impulses give rise to a climatic effect of a single type throughout the area, and finds conclusive evidence of a true solar periodicity, which leads him to remark that Newcomb has not done full justice to his criterion. When two different phenomena are related simply by coincidence of a maximum, it takes a great many recurrences to completely establish the connection; but where the relation includes further details in respect to congruous curves, this is equivalent to an indefinite multiplication of coincidences and the relation may be discerned from comparatively few observations.

Criteria are also needed in other departments of solar radiation study to decide upon the permissible limits of deduction. Questions have arisen as to the proper times and stations for actinometric measurements which can be settled in no other way than by means of decisive criteria or crucial tests. The Smithsonian observations, for example, usually stop when the air mass becomes as large as 3 or 4 atmospheres. Some do not even extend to 2 atmospheres. Reduced by Bouguer's formula, these midday readings agree among themselves, but solely because they have stopped before reaching the point where disagreement begins. This is equivalent to shirking the difficulties, and the seeming extraordinary agreement of the measures is misleading. If the missing readings had been supplied, the discrepancies would have been obvious.† Such

* Frank H. Bigelow: "Studies in the General Circulation of the Earth's Atmosphere," this Journal (4), vol. xxix, p. 277, April, 1910.

† In Abbot's work on "The Sun," in the pages devoted to the solar constant, one looks in vain for even the bare mention of the names of Forbes, Violle, Crova, Langley, Hanski, Savélieff and many others whose work has helped to solve this greatest of astrophysical problems. The only name mentioned by Mr. Abbot in this connection is that of Pouillet, whose results resemble his own, while those passed by in silence totally disagree.

It is not always possible to secure complete series of actinometric observations, but this does not absolve us from the duty of trying to make them. The fine work of Mr. H. H. Kimball, who, on several occasions, has followed the sun almost or quite to its setting, and whose actinometric measurements have been of great assistance to me, deserves especial mention by way of contrast, and the splendid services of M. Crova to this study will never be forgotten.

incomplete observations are incapable of elucidating the laws of atmospheric absorption except through the aid of more perfect measures. By supplying deficiencies under guidance of a criterion we may in some cases rescue observations which are otherwise useless.

It will sometimes be necessary to discard imperfect or discrepant observations on good and sufficient grounds, and to select the most suitable material for discussion, but the principle of selection must be a rational one, capable of concatenation with known facts in other departments of scientific investigation and, if possible, one which can be subjected to some critical check. The new thermodynamics of the atmosphere promises to provide such a check on the problems of solar radiation.

The conclusion that the equivalent of the solar constant of radiation can not be less than three, though it may be as much as four gram-calories per sq. cm. per minute, has now been forced upon us in many ways. It is of prime importance that we recognize the existence of a special region of peculiarly potent incipient absorption of solar radiation in the upper air, whereby the upper fourth of the atmosphere of oxygen and nitrogen with its contained aqueous vapor becomes a reservoir of thermal energy and a protective covering for the deeper layers.* This great upper nonadiabatic layer of permanent temperature-inversion is comparatively quiet as to air movement, is free from storms, and maintains an almost constant average temperature in summer and winter irrespectively; but thermally this region is the most actively changing in the entire atmosphere. Here occur the widest fluctuations of temperature to be found at any level in the free air within intervals of a few days.† It is here that a very large fraction of the solar radiation disappears, so that a radiant equivalent which may be 3.5 cal. /sq. cm. min. at the atmospheric limit (or possibly even 4) is reduced to less than 2 by the time that the rays strike the tops of some of our highest mountains. In this great isothermal layer also resides the radiant power of the atmosphere. The heat absorbed here from the sun's rays is again lost by radiation to space, and does not appear in our sea-level observations of solar radiation, nor even in those made on mountains. Abbot's hypothetical radiant layer at 4000 meters simply does not exist, but a value of the solar constant

* See Frank W. Very, "Sky Radiation and the Isothermal Layer," this Journal (4), vol. xxxv, p. 369, April, 1913.

† On account of this peculiarity it has been proposed to abandon the earlier name—"isothermal layer"—in favor of the rather meaningless term, "Stratosphere"; but the absence of a seasonal fluctuation of temperature still makes the older name appropriate.

greater than three requires that a considerable part of the earth's heat shall be lost from *an atmospheric layer having the temperature of the isothermal layer* and thus coincides with the known phenomena of the upper air.* When we add that many other facts, such as the observed temperature of the moon,† and the melting of the polar snows on the planet Mars, as well as my measurement of the precipitable water vapor in its atmosphere‡ which confirms the temperature assigned by Lowell to Mars,§ all demand an equivalent of solar radiation of this order of magnitude, the larger value of the solar constant appears to be thoroughly established.

Westwood Astrophysical Observatory,
Westwood, Massachusetts,
November, 1912.

* Frank W. Very: "On the Need of Adjustment of the Data of Terrestrial Meteorology and of Solar Radiation, and on the Best Value of the Solar Constant," *Astrophysical Journal*, vol. xxxiv, pp. 385-386, December, 1911.

† Frank W. Very: "The Probable Range of Temperature on the Moon," *Astrophysical Journal*, vol. viii, pp. 199-217, and 265-286, November and December, 1898. Also "Note on the Temperature Assigned by Langley to the Moon," *Science*, N. S., vol. xxxvii, No. 964, pp. 949-957, June 20, 1913.

‡ Frank W. Very: "Measurements of the Intensification of Aqueous Bands in the Spectrum of Mars," *Lowell Observatory Bulletin* No. 36, vol. i, pp. 207-212. "Water Vapor on Mars," do. No. 43, vol. i, pp. 239-240. "New Measures of Martian Absorption Bands on Plate Rm 3076," do. No. 49, vol. i, pp. 260-262. See also *Science*, N. S., vol. xxix, pp. 191-193; vol. xxx, pp. 678-679; vol. xxxii, pp. 175-177.

§ Percival Lowell: "Temperature of Mars," *Proc. American Acad. of Arts and Sciences*, vol. xlii, No. 25, pp. 651-667, March, 1907.

ART. LV.—*A New Occurrence of Cuprodescloizite*,* by
ROGER C. WELLS.

A MINERAL recently received for inspection by the United States Geological Survey was provisionally identified as cuprodescloizite. It was collected by Philip D. Wilson of Bisbee, Arizona, who stated that it is found in some quantity in the Shattuck Arizona mine in Bisbee, and that it is the first occurrence of a vanadium mineral noted in that district. On account of its unusual form and composition, an analysis seemed advisable and for this purpose Mr. Wilson generously placed a large amount of material at the disposal of the Chemical Laboratory of the Survey.

General description.—The mineral occurs in the form of stalactites. The smaller aggregates radiate from a narrow base and end in rounded clusters 1–8^{mm} in diameter. The larger growths occur in reniform masses several centimeters in diameter. The latter are coated with a red powder, but the smaller aggregates have an olive hue. The fractured surface of all varieties possesses a dark brown luster and shows a radiating structure. The streak is “dark olive-buff,” Plate XL of Ridgeway’s color standards,† and the powder somewhat darker.

Dr. W. T. Schaller has kindly made the following observations upon the optical properties: “The broad fibers have parallel extinction. The elongation is *X*. The pleochroism is marked: parallel elongation, yellow; normal thereto, brown. Absorption, brown > yellow. Refractive indices high, greater than 1.74. Birefringence strong, estimated 0.03 to 0.04. Indications of biaxiality were seen, but the individual crystal units were too small to permit of any definite results being obtained.”

Chemical Investigation.—The mineral was almost completely soluble in dilute nitric acid. The small insoluble portion was found to be chiefly lead chromate, soluble in more concentrated nitric acid after decantation of the main solution. Hydrochloric acid transposed the mineral into lead chloride, copper chloride and vanadic acid. Sulphuric acid decomposed it with precipitation of lead sulphate. Lead was determined as sulphate, either after separation as sulphide, or after direct precipitation as sulphate. Copper was determined as metal after separation as sulphide and electrolysis. Lead and copper having been removed by a rapid stream of hydrogen-sulphide, arsenic was separated as sulphide after one to three days

* Published with the permission of the Director of the United States Geological Survey.

† Robert Ridgeway, “Color Standards and Nomenclature.” Washington, D. C., 1912.

reduction of the arsenate in a closed flask, while vanadium remained in solution in the quadrivalent state. After boiling out all hydrogen-sulphide and heating for some time, sodium carbonate was added in slight excess, thus precipitating chromium and zinc. The latter precipitate was ignited, fused with sodium carbonate, and the melt extracted with water. Zinc was determined in the insoluble portion by separating as sulphide and weighing as sulphate. Chromium was precipitated in the water portion by adding a slight excess of nitric acid and a large excess of lead nitrate and the lead chromate weighed as such after drying at 110°. Vanadium was determined in sulphuric acid solution by reduction with H_2S or SO_2 and titration with KMnO_4 , the small amount of vanadium carried down with the copper being separately determined. As a check vanadium was also determined by the method recommended by Cain and Hostetter,* which yielded a slightly higher result than by the first method, viz. 21.73 per cent instead of 20.95. No other elements could be discovered in significant amounts. There was no hygroscopic water at 105° C. In order to see if the mineral had lost water by exposure to a dry atmosphere it was kept in a moist atmosphere for two weeks. No notable absorption of water occurred.

ANALYSIS.

	1	2	3	Mean	Molecular values
Insol.	·16	·18	----	·17	---
PbO	55·34	55·78	55·80	55·64	·251
CuO	17·04	16·99	17·13	17·05	·214
ZnO	·28	·34	----	·31	·004
V_2O_5	20·57	21·33	21·73	21·21	·116
As_2O_5	1·40	1·24	1·35	1·33	·006
P_2O_5	·24	----	----	·24	·002
CrO_3	·57	·42	----	·50	·005
H_2O	3·63	3·51	----	3·57	·198

100·02

Discussion of Analysis.—On comparing the analysis with those of well-recognized species, the mineral is found to be best described by the name cuprodescloizite. Two interesting facts appear. The percentage of copper is higher than in any variety of cuprodescloizite hitherto reported and there is a small amount of chromium. Although the proportion of copper suggests psittacinite, it seems probable, in view of the variable amounts of lead and water reported in psittacinite, that the latter mineral is an alteration product of descloizite. The present mineral, it is true, has an excess of water over the

* J. R. Cain and J. C. Hostetter; A rapid method for the determination of vanadium in steels, ores, etc. J. Ind. and Eng. Chem., iv, 250, 1912.

requirements of the formula $2\text{PbO} \cdot 2\text{CuO} \cdot \text{V}_2\text{O}_5 \cdot \text{H}_2\text{O}$ and a deficiency of copper, as shown by the following comparison :

	Theory for $\text{PbVO}_4 \cdot \text{CuOH}$	Found
PbO	55.4	55.6
CuO	19.8	17.0
ZnO	---	.3
V_2O_5	22.6	21.2
As_2O_5	---	1.3
P_2O_5	---	.2
H_2O	2.2	3.6
	<hr/> 100.0	<hr/> 99.2

The lead content, however, agrees very well with that required for cuprodescloizite. It is evident that the elements of the minerals of the olivinite group often suffer extensive replacement. Here we have copper appearing almost wholly in place of the zinc of descloizite, the intermediate members being already known. The present mineral, then, represents the copper end of the cuprodescloizite series. It may be that the entrance of the copper favors the addition of another molecule of water. Several investigators have commented on the tendency of the minerals of this series to carry a slight excess of water which is certainly not hygroscopic.* Chromium has not been reported in any descloizite heretofore. It suggests a slight admixture of a compound analogous to vanuelinite.

Genesis.—The constituents of this mineral, lead, copper, vanadium, arsenic, etc., in combination yield “insoluble” compounds and were, therefore, probably assembled in very dilute solutions.

The stalactitic form of the mineral indicates that it crystallized by the evaporation of downward migrating solutions and its chemical character shows that the solutions were products of oxidation. With the data at hand it is impossible to ascribe any special geologic significance to its origin. Its chemical composition, however, is significant. Since the chromate of lead is very insoluble like the vanadate, it is evident that vanadium was present in the solution in excess of chromium. Some tentative experiments have shown that when lead and copper compete for a soluble vanadate, lead vanadate is the principal product. Hence it seems reasonable to assume that lead was scarcer than copper in the solution from which the mineral formed. With present data it is impossible to make any definite statement, however, about the proportion of vanadium with respect to the copper in the mother solution.

* Cf. Penfield, this Journal, xxvi, 364, 1883.

ART. LVI.—On the Crystallization of Willemite; by
CHARLES PALACHE and R. P. D. GRAHAM.

THE form series of willemite has hitherto been small and few accurate measurements of its crystals have been recorded. In a brief note in this Journal, xxix, 1910, one of the authors gave observations made on crystals from Franklin Furnace, N. J., which were believed superior to those previously obtained and proposed a new axial ratio based upon them. Crystals from the same locality recently secured for the Harvard Mineralogical Museum through Mr. Lazard Cahn give a far better series of measurements as well as a number of forms new to the mineral, and it is the purpose of this paper to present these new facts.

The crystals which are minute, not exceeding a millimeter in diameter, are of prismatic habit and perfectly transparent, colorless, or of a pale yellowish-green tint. They are implanted upon rhodochrosite which is in part gray and massive, in part pale pink and well crystallized in curved unit rhombohedrons. Most of the crystals are singly terminated, but several were noted and one measured which showed identical characteristic third order rhombohedrons on both extremities with no suggestion of hemimorphism as indicated for the mineral by Canfield.† Many of the crystals on these specimens are dull and lusterless by reason of slight etching and the deposit of a thin coating of some earthy substance upon them. But the measured crystals are brilliant, and except for the small size of some of the faces leave nothing to be desired in the quality of the signal reflections.

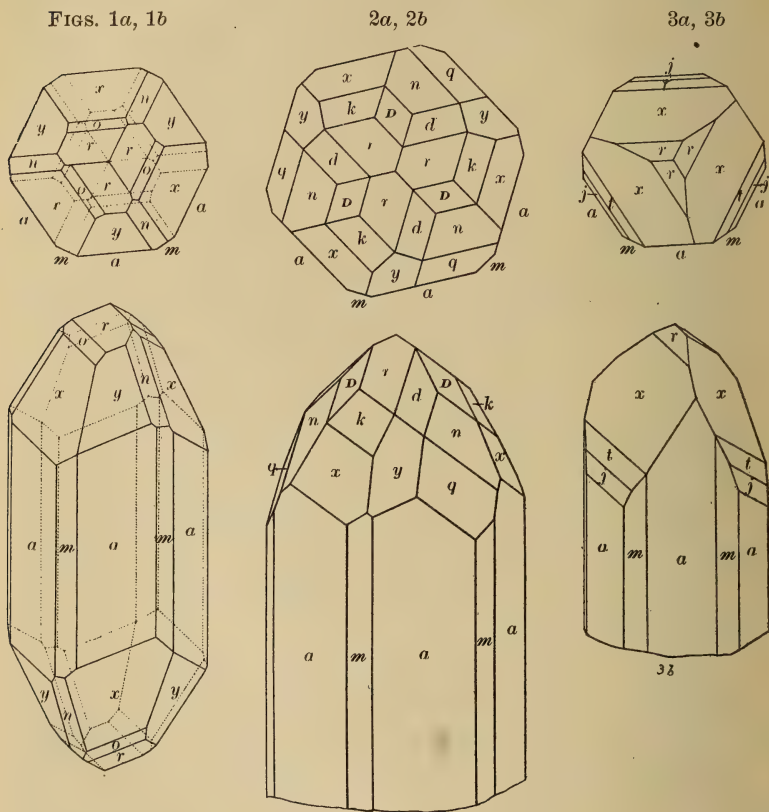
The forms observed on the six measured crystals are :

Letter	Symbol G ₂	Symbol Bravais	Letter	Symbol G ₂	Symbol Bravais
<i>a</i>	$\infty 0$	(11 $\bar{2}$ 0)	<i>x</i>	+41 (<i>l</i>)	(3 $\bar{1}$ $\bar{2}$ 1)
<i>m</i>	∞	(10 $\bar{1}$ 0)	<i>y</i>	+41 (<i>r</i>)	(21 $\bar{3}$ 1)
<i>r</i>	+1	(10 $\bar{1}$ 1)	* <i>j</i>	+10.1 (<i>l</i>)	(7 $\bar{3}$ 41)
* <i>n</i>	-2	(02 $\bar{2}$ 1)	* <i>i</i> (?)	+10.1 (<i>r</i>)	(43 $\bar{7}$ 1)
<i>u</i>	10(<i>l</i>)	(2 $\bar{1}$ $\bar{1}$ 3)	* <i>d</i>	-2 $\frac{1}{2}$ (<i>l</i>)	(12 $\bar{3}$ 2)
<i>s</i>	01(<i>r</i>)	(11 $\bar{2}$ 3)	* <i>D</i>	-2 $\frac{1}{2}$ (<i>r</i>)	(1 $\bar{3}$ $\bar{2}$ 2)
* <i>o</i>	+21(<i>l</i>)	(5 $\bar{1}$ 43)	* <i>q</i>	-52 (<i>l</i>)	(1341)
* <i>k</i>	+ $\frac{5}{2}$ 1(<i>l</i>)	(4 $\bar{1}$ $\bar{3}$ 2)	* <i>l</i>	-74 (<i>l</i>)	(15 $\bar{6}$ 1)

* The asterisk indicates new forms.

† This Journal, xxiii, 20, 1907.

Fig. 1 shows the prevailing type with the prism a dominant and narrow truncating faces of m ; while the characteristic terminal planes are the complementary positive third order rhombohedrons x and y and the first order rhombohedrons r and n . The crystal shown in fig. 2 has in addition largely developed faces of the negative third order rhombohedrons d ,



D and q . The criterion used to determine a common position for the various measured crystals was the occurrence of the third order rhombohedrons k and o , one or both of which are always present, and by producing a faint striation on x parallel to the intersection with a , give a sure means of orientation. The forms q and l when present can also be thus used without ambiguity. The figures are representative of types rather than particular crystals; although there is much variation in the relative size of the different forms, the draw-

ings do not exaggerate the regularity of development of the most perfect crystals.

The combinations presented by the measured crystals with the number of faces of each form observed are contained in Table I. The last crystal alone was doubly terminated.

FIG. 4

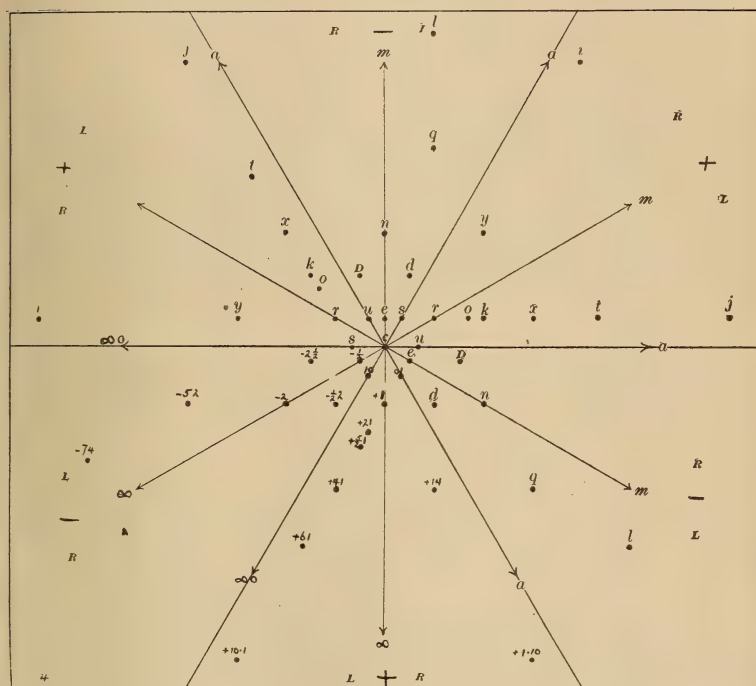


TABLE I.

Crystal	a	m	r	n	u	s	o	k	x	y	j	i	d	D	q	l
1	6	6	3	3	1	1	—	3	3	3	—	—	2	3	3	1
2	6	6	2	3	—	—	1	3	3	3	1	—	2	2	3	3
3	6	6	2	1	1	—	1	2	3	3	—	—	1	1	—	—
4	6	6	2	2	—	—	—	2	3	3	2	1	2	3	—	—
5	×	×	×	×	—	—	×	×	×	×	—	—	—	—	×	—
6	6	6	5	1	2	2	2	3	3	5	—	—	2	2	2	—

Of the forms not shown in the drawings the second order rhombohedrons u and s occur rarely as minute faces modifying the extreme summit of the crystals; the third order rhombohedrons j , i , and l , are line faces truncating the edges of intersection of x , y , and q with the prisms. The form i , based on a single poor reading, is doubtful.

Table II presents a summary of the measurements obtained and the values of p_0 calculated from the individual forms. In this table the complementary forms x and y , d and D are united for the sake of brevity and the observed angles for ϕ are reduced to a single sectant. The calculated angles based on the derived value of p_0 are also included. This value is based on the 50 best readings from faces of the 7 forms placed first in the table. The value of p_0 is .4453 corresponding to the axial ratio $a:c = 1:6679$. This value is very nearly the same as that of Lévy calculated from measurements of crystals from Moresnet and differs quite widely from the one to which reference has been made, proposed by Palache and based on poorer crystals.

Lévy-Moresnet.....	$a:c = 1:6696$	$p_0 = .4464$
Palache and Graham F:F..	" 1:6679	$p_0 = .4453$
Palache 1910 " "	" 1:6612	$p_0 = .4408$

TABLE II.

Letter	Symbol G_2	Measured		Limits		No. of readings	Quality	Value of p_0 calculated	Calculated	
		ϕ	ρ	ϕ	ρ				ϕ	ρ
r	+1	29°59'	37°41'	29°52'–30°06'	37°39'–37°42'	8	Best	.4459	30°00'	37°39'
n	–2	30 00	57 03	29 57–30 04	57 00–57 06	5	"	.4451	"	57 03
k	–1	16 07	54 17	15 57–16 17	54 14–54 21	6	"	.4455	16 06	54 17
$x \& y$	41	10 52	63 57	10 47–10 58	63 52–64 05	23	"	.4453	10 54	63 53
$d \& D$	–2½	10 54	45 36	10 50–11 01	45 34–45 41	9	"	.4446	10 54	45 34
o	21	19 14	49 30	19 04–19 29	49 00–49 47	5	poor	----	19 06	49 41
j	10·1	4 41	77 49	4 35–4 52	77 46–77 54	3	"	----	4 43	77 58
$i(?)$	10·1	5 27	77 37	-----	-----	1	"	----	"	"
q	–52	16 03	70 19	15 47–16 19	70 02–70 38	9	fair	----	16 06	70 13
l	–74	20 48	76 51	20 32–21 00	76 45–76 58	4	poor	----	21 03	76 54

In addition to the new forms determined on these crystals observations had previously been obtained on other poorer crystals from Franklin Furnace establishing the forms n , x , and j , and two additional forms, one of which is shown in fig. 3. These measurements follow:

		Measured	
		ϕ	ρ
$t + 61(l)(13\cdot5\cdot8\cdot3)$	-----	7°30'	71°53'
		7 20	71 30
Calculated	-----	7 35	71 07
$w + 16\cdot1(l)(14\cdot5\cdot9\cdot1)$	-----	3 03	82 07
		3 01	82 30
Calculated	-----	3 00	82 17

The relations of the forms found on the Franklin Furnace willemite are well brought out in the gnomonic projection, fig. 4, in which they are plotted and the positive and negative sectants with the right and left subdivisions are indicated. The most striking feature of the form development is the marked nature of the rhombohedral-tetartohedrism, more pronounced even than in phenacite. There is, moreover, the greatest

TABLE III.

Letter	Symbol		ϕ	ρ	Localities			
	G ₂	Bravais			Moresnet	Franklin Furnace	New Mexico*	Greenland†
<i>c</i>	0	(0001)	00°00	00°00'	×	×	×	×
<i>a</i>	∞0	(1120)	00 00	90 00	---	×	×	×
<i>m</i>	∞	(1010)	30 00	90 00	×	×	---	×
<i>f</i>	3∞	(5270)	-46 06	90 00	---	---	---	×
<i>h(?)</i>	4∞	(3120)	-10 54	90 00	---	×	---	---
<i>u</i>	10(<i>l</i>)	(2113)	00 00	24 00	---	×	×	×
<i>s</i>	01(<i>r</i>)	(1123)	60 00	24 00	---	×	---	×
<i>e</i>	- $\frac{1}{2}$	(0112)	30 00	21 05	---	×	×	×
<i>p</i>	+\frac{1}{2}	(3034)	-30 00	30 03	×	---	---	---
<i>r</i>	+1	(1011)	"	37 39	---	×	×	×
<i>z</i>	-1	(0111)	30 00	37 39	---	---	×	---
<i>n</i>	-2	(0221)	"	57 03	---	×	---	---
<i>v</i>	-\frac{4}{3}\frac{1}{3}(<i>r</i>)	(1325)	10 54	23 11	---	---	×	---
<i>o</i>	+21(<i>l</i>)	(5143)	-19 06	49 41	---	×	---	---
<i>k</i>	+\frac{5}{3}1(<i>l</i>)	(4 32)	-16 06	54 17	---	×	---	---
<i>x</i>	+41(<i>l</i>)	(3121)	-10 54	63 53	---	×	---	×
<i>y</i>	+41(<i>r</i>)	(2131)	-49 06	63 53	---	×	---	×
<i>t</i>	+61(<i>l</i>)	(13·5·8·3)	- 7 35	71 07	---	×	---	---
<i>j</i>	+10·1(<i>l</i>)	(7341)	- 4 43	77 58	---	×	---	---
<i>i(?)</i>	+10·1(<i>r</i>)	(4371)	-55 17	77 58	---	×	---	---
<i>w</i>	+16·1(<i>l</i>)	(14·5·9·1)	- 3 00	82 17	---	×	---	---
<i>d</i>	-2½(<i>l</i>)	(1232)	49 06	45 34	---	×	---	---
<i>D</i>	-2½(<i>r</i>)	(1322)	10 54	45 34	---	×	---	---
<i>q</i>	-52(<i>l</i>)	(1341)	43 54	70 13	---	×	---	---
<i>l</i>	-74(<i>l</i>)	(1551)	38 57	76 54	---	×	---	---

* Penfield, this Journal, xlvii, 305, 1894.

† Boeggild, Mineral. Groenland, p. 276, 1905.

similarity with the latter mineral not only in type of symmetry but in the actual forms and in their angles. The new axial ratio of willemite is almost identical with that of phenacite.

Willemite	-----	$p_o = .4453$	$a : c = 1 : .6679$
Phenacite	-----	$p_o = .4407$	$a : c = 1 : .6611$

In Table III is given a complete angle-table for willemite, calculated for the new axial ratio. The angle ϕ given for each form is that of the face nearest in azimuth to the right hand face of a , taken as zero (see fig. 4). There is also added a tabulation of the localities from which crystals have been described, the forms found at each place being indicated.

Harvard Mineralogical Laboratory,
Cambridge, Mass., July, 1913.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Action of Sulphur Trioxide upon Salts.*—Many years ago H. Rose observed that dry potassium chloride absorbs the vapor of sulphuric anhydride without giving off any gas, forming a compound that reacts violently with water. A similar behavior of several other salts has been observed by others, but the compounds formed have not been satisfactorily investigated. W. TRAUBE has now made a further study of this subject. He found that sodium chloride takes up two molecules of sulphuric anhydride, forming $\text{NaCl} \cdot 2\text{SO}_3$, which from its reactions he showed to be the sodium salt or chlor-pyrosulphonic acid, $\text{O} < \begin{smallmatrix} \text{SO}_2 - \text{ONa} \\ \text{SO}_2 - \text{Cl} \end{smallmatrix}$.

A corresponding compound was formed with ammonium chloride and sulphur trioxide. These compounds react violently with water, giving off hydrochloric acid and forming strongly acid solutions. With sodium and ammonium fluorides sulphuric anhydride gave products which were very remarkable from the fact that they dissolved in water without producing heat and gave almost neutral solutions which reacted neither for fluorides nor for sulphates. The compounds were found to be fluorsulphonates, NaSO_3F and $\text{NH}_4\text{SO}_3\text{F}$. When these salts were treated with strong sulphuric acid the free fluorsulphonic acid HSO_3F could be distilled off, and it was found that this acid could be readily prepared by passing hydrofluoric acid gas into fuming sulphuric acid.—*Berichte*, xlvii, 2513.

H. L. W.

2. *Volumetric Determination of Fluorine*.—ALFRED GREEF has devised a new volumetric method for the determination of fluorine, which promises to be important, since heretofore the determination of this element has presented many difficulties. Thus far the method has been worked out only for compounds soluble in water. It is based upon the fact that in a neutral solution of sodium fluoride the addition of ferric chloride produces a precipitate of "ferric cryolite," Na_3FeF_6 , which does not react with potassium sulphocyanide to produce a red color. The end reaction is not sharp, however, except under special conditions. The solution must be neutral to phenolphthalein. A volume of 25^{cc} in an Erlenmeyer flask is recommended. Then 20^g of pure sodium chloride and 1^g of potassium sulphocyanide are added and it is titrated with a ferric chloride solution, made from the commercial salt and containing such an amount of iron that 1^{cc} is equivalent to 0.01^g of NaF, until a pale yellow color is produced. Then 10^{cc} each of alcohol and ether are added, the liquid is shaken up once while the flask is open, then a stopper is put in and the liquid is shaken thoroughly until, after further addition of ferric chloride, the ether layer no longer loses its red color upon shaking and standing. Mixtures of sodium fluoride with acid sodium fluoride and sodium silicon fluoride may be analyzed by first titrating in a platinum dish, hot, with decinormal sodium hydroxide, with phenolphthalein as indicator, thus measuring the effect of the two other things together, then determining the total sodium fluoride as previously described. In another portion the acid fluoride is determined by titration with sodium hydroxide after the addition of potassium chloride and alcohol amounting to about one-half of the final volume. The test analyses given by the author show very satisfactory results, both for sodium fluoride alone and for the mixtures.—*Berichte*, xli, 2511. H. L. W.

3. *The Behavior of Hydrogen towards Palladium*.—Since there are conflicting statements in the literature in regard to the volume of hydrogen absorbed by palladium at low temperatures, GUTBIER, GEBHARDT, and OTTENSTEIN have made a new investigation of this subject. Using spongy palladium which had been prepared very carefully, they saturated it with hydrogen at various temperatures, then after removing the excess of hydrogen by means of a current of carbon dioxide, they drove off the hydrogen by ignition and measured it. They found a minimum absorption at 20° C. of 661 volumes of hydrogen, which increased gradually to 917 volumes at -50° C., and which increased more slowly to 754 volumes at 105° C.—*Berichte*, xli, 1453. H. L. W.

4. *A New Era in Chemistry*; by HARRY C. JONES. 12mo, pp. 326. New York, 1913 (D. Van Nostrand Company). Price \$2.00 net.—This work gives an account of the more important developments in general chemistry during the last quarter of a century—the development, in fact, of modern physical chemistry. The discussion necessarily includes some account of older theories in order that the recent work may be more thoroughly explained.

It is a very interesting book, and it will be extremely useful, not only to students of the present day as a clear and simple treatment of the subject, but it is also a very suitable source of information for those whose knowledge of chemistry has not been brought up to the present time. From the fact that Professor Jones has studied with three leaders of the modern movement—Van't Hoff, Arrhenius, and Ostwald, he is particularly competent to discuss their work and achievements. In an appendix he has given some very interesting personal reminiscences of Mendeléeff, Kekulé, Willard Gibbs, Van't Hoff, Arrhenius, and Ostwald.

H. L. W.

5. *Experiments Arranged for Students in General Chemistry*; by EDGAR F. SMITH and HARRY F. KELLER. 12mo, pp. 56. Philadelphia, 1913 (P. Blakiston's Son & Co. Price 60c. net).—This is a laboratory book for beginners in chemistry, involving a short course in the subject. It is intended to be used with any text-book. It not only describes experiments, but asks many questions in connection with them. The experiments appear to be very well chosen, and the numerous questions should be very useful in helping the student to gain valuable knowledge from the course of laboratory work.

H. L. W.

6. *Chemical German*; by FRANCIS C. PHILLIPS. 8vo, pp. 241. Easton, Pa., 1913 (The Chemical Publishing Co.).—This book gives simple exercises for practice in translating chemical German; it explains the nomenclature, contains a collection of very well selected, interesting extracts from chemical writings, and includes a vocabulary of technical and other words. It appears to be an excellent book for the purpose of aiding our advanced students in the somewhat difficult matter of applying their school German to chemical literature.

H. L. W.

7. *Spectrum of the Aurora Borealis*.—In order to obtain, if possible, more accurate data relating to the northern lights, an expedition to Bossekop in Finmark was made during the winter of 1912–13 by L. VEGARD. With a direct-vision spectroscope 28 observations of the green line were made and the mean of the settings gave, when reduced, a wave-length of 5573.7 \AA . The stronger auroral displays made it possible to distinguish a few lines in the blue. The two most intense lines could alone be studied quantitatively and the wave-lengths were found to be 5271.5 and 4708.3 for the weaker and stronger lines respectively. Several faint lines in the neighborhood of $\lambda 5271$ were discernible.

The most reliable data were obtained photographically by means of a prism spectrograph having a dispersion between $H\beta$ and $H\gamma$ five times as great as had ever been used before on the same problem. Four spectrograms were obtained, the shortest time of exposure being 10 hours and the longest 1 month. The mean wave-lengths derived from the plates are 5571.3 , 4708.0 , 4646.8 , 4278.0 , 4234.2 , 4200.3 , and 3914.6 . The average of the numbers 5573.7 and 5571.3 (as obtained by the visual and photographic methods respectively), namely 5572.5 , agrees very well

with the wave-length (5572·6) of one of the stronger argon lines. The wave-lengths of the prominent heads of the nitrogen band spectrum are 4708·2, 4651·2, 4278·0, 4236·3, 4200·9, and 3914·4. A comparison of these values with the figures given above for the auroral lines leaves no doubt as to the origin of the radiations in question. Moreover a weak comparison photograph of the negative glow of nitrogen, taken with the same apparatus, showed that the distribution of intensity of the strongest "lines" (4708, 4278, 3914) was the same as in the spectrum of the northern lights. Also, the most intense of these auroral lines (4278) shades off on the more refrangible side precisely as does the corresponding nitrogen band. Unfortunately the lines which were of sufficient intensity to be measured are not numerous enough to decide the question as to whether auroræ are caused by electronic rays or by rays of the α type.—*Physik. Zeitschr.*, No. 15, August 1913, p. 677.

H. S. U.

8. *To Produce a Continuous Spectrum in the Ultra-violet.*—Investigators of absorption spectra have long felt the need of a source of intense, continuous radiation in the ultra-violet. This is especially true in the case of fine absorption lines as given by gases and vapors. The sources of continuous ultra-violet light hitherto found have had little practical value because of their faintness, or of their great inconvenience, etc. It is pointed out in a short paper by VICTOR HENRI that if a spark of high frequency, such as is used in the Tesla and d'Arsonval experiments, is employed instead of the usual condensed spark, excellent results can be obtained. The spark gap must be under water and the electrodes are preferably made of aluminium. A spark 4 or 5^{mm}s long may be readily produced and it is said to be very constant. With an exposure of only 30 to 60 secs. the continuous spectrum extends to about wave-length 2150 Å. The spectrogram reproduced in the plate is unusually good. The continuity of the spectrum is broken in a few places by intense lines and by narrow reversals. In general, this lack of perfect continuity would not be a practical drawback.—*Physik. Zeitschr.*, No. 12, June 1913, p. 516.

H. S. U.

9. *The Gyroscope*; by F. J. B. CORDEIRO. Pp. vii, 105, with 19 figures. New York, 1913 (Spon and Chamberlain).—The justification of the production of a new book on gyroscopic phenomena is expressed by the author in the following words: "The student with an elementary knowledge of mathematics, who attempts to understand gyroscopics from a study of its scattered parts in standard treatises, and from the few monographs as yet written, will find the task tedious—probably repulsive." "For this reason, it has seemed advisable to the author to write a monograph which may be easily understood by anybody possessing an elementary knowledge of mechanics and the calculus." The book is divided into two parts which deal respectively with the development of the theory from the fundamental gyroscopic equation $C\omega\dot{\theta} = A\ddot{\psi}$, and with the practical applications of the

principles to the Griffin grinding mill, the Howell torpedo, the Obry device, the Schlick stabilisator, the Brennan monorail, the Anschütz compass, ballistics, astronomy, geology, and meteorology. The subject-matter is so presented that the astronomical discussions may be omitted without loss of continuity. The text has been prepared with care and there is no hesitancy in the expression of opinion concerning modern terminology, etc. For illustration: "The term gyrostat, often used for gyroscope, is particularly objectionable." "There is no such thing as a gyrostat, or instrument which maintains its plane of rotation." Again: "The word '*Torque*' is engineering '*slang*' for couple." "It should never be used." Although the book seems excellent in itself, some doubt exists in the mind of the reviewer as to whether a student possessing only "an elementary knowledge of mechanics" would be prepared to read all of the theoretical sections. In one place (p. 38), at least, a proof depends on the reference in Routh's *Advanced Dynamics*, Art. 519. Problems for solution by the student are not given in this volume. H. S. U.

10. *Medizinische Physik*; by Dr. OTTO FISCHER. Pp. xx, 1120, with 334 figures. Leipzig, 1913 (S. Hirzel).—In this work the author has endeavored to present, in such a manner as to be readily comprehended by those who are not proficient in mathematics, certain branches and topics of physics which lie outside of the realm of the ordinary curriculum and which are nevertheless indispensable for the physician. In order to give the book finite dimensions the treatment is wisely restricted to the physical aspect of the subject, so that everything of a physical-chemical or purely physiological nature has been omitted. The average physician's training in physics is considered to need appreciable supplementing only in three branches, namely, mechanics, acoustics, and optics. That these three domains are discussed at great length may be inferred from the fact that 475, 124, and 521 pages are devoted to each of the general subdivisions in the order named. In mechanics, the conception of the differential calculus is very painstakingly introduced and elementary differential quotients are subsequently used. The author intends not to avoid mathematical and other difficulties but rather to show how these difficulties may be overcome by forming correct physical conceptions of the problems under consideration. Furthermore, the volume is not designed as a reference book, on the contrary, it is prepared only for consecutive reading. To this end no index is given although a detailed table of contents is incorporated. The text-figures were made from the author's own drawings and hence they invoke the precise mental and ocular impressions intended. The book is undoubtedly thorough and complete but its unusual extent may militate against its usefulness. H. S. U.

11. *The Wonders of Wireless Telegraphy*; by J. A. FLEMING. Pp. xi, 279, with 54 figures. London, 1913 (Society for Promoting Christian Knowledge).—This volume is a companion to the author's little book on "Waves and Ripples." "The present

work is therefore not intended for technical students or practical wireless telegraphists, . . . but is put forward (with diffidence) as a little attempt to furnish the general reader with a fairly non-technical account of the underlying principles and practical achievements of wireless telegraphy, and of the wonders which it has rendered possible in the transmission of intelligence." The first chapter deals with the luminiferous ether, electricity and electrons, and the second with electric oscillations and electric waves. Since there are six chapters in all, it is thus seen that every precaution has been taken to prepare the reader for a full understanding of the four chapters which relate directly to wireless telegraphy and telephony. The text is up to date and trustworthy, the historical side of the subject is presented in a complete and fascinating manner, and it seems difficult to imagine a better book for the non-mathematical reader. H. S. U.

12. *The Principles and Methods of Geometrical Optics, Second Edition*; by JAMES P. C. SOUTHALL. Pp. xxiv, 663, with 175 figures. New York, 1913 (The Macmillan Co.).—For a review of the first edition of this standard work see this Journal, vol. xxxi, p. 233 (1911). The modifications which the earlier edition has undergone may be briefly stated as follows: P. viii a, a list of recent books on optics is given. Art. 15, on "Character of a Bundle of Optical Rays", has been rewritten. § 51, supplemented by p. 50d. § 102, on "Deviation (D) of Ray Obliquely Refracted through a Prism", rewritten. Chapter X has § 229a added. It is headed "Trigonometric Formulae of M. Lange for Calculating the Path of an Oblique Ray through a Centered System of Spherical Refracting Surfaces". An appendix of 15 pages has been added to chapter XI. The next chapter has been augmented by § 326a and by an 11-page "Note on the Calculation of the Spherical Errors of an Optical System of Centered Lenses, by Means of the Seidel Formulae". Pages 612a and 612b comprise a list of new letters and symbols. The volume ends with a supplementary index. It is therefore evident that the author and publishers are sparing no pains to make the book converge towards practical perfection as rapidly as possible. H. S. U.

13. *Physical Measurements*; by A. WILMER DUFF and ARTHUR W. EWELL. Third edition. Pp. xii, 244, with 80 figures. Philadelphia, 1913 (P. Blakiston's Son & Co.).—For earlier notices of this excellent book see this Journal, vol. xxvii, p. 488 (1909) and vol. xxx, p. 350 (1910). "With the exception of the introduction of a second method for the measurement of viscosity, no considerable changes will be found in this edition; but numerous minor improvements have been made in the descriptions of apparatus and methods". H. S. U.

14. *Über kausale und konditionale Weltanschauung und deren Stellung zur Entwicklungsmechanik*; by WILHELM ROUX. Pp. 66. Leipzig, 1913 (Wilhelm Engelmann).—In this critical essay the author adduces a very great number of arguments to show that the "Konditionismus" of Max Verworn is utterly worthless. "Statt der angekündigten, neue Erkenntnis bringenden Weltans-

chauung fanden wir Irrtum und Verwirrung." "Die Weltanschauung M. VERWORNs würde, wenn sie richtig wäre, statt Licht Dunkel verbreiten."

H. S. U.

15. *Annals of the Astrophysical Observatory of the Smithsonian Institution*; by C. G. ABBOT, Director, F. E. FOWLE and L. B. ALDRICH. Vol. III, pp. xi, 241, with 7 plates and 32 figures. Washington, 1913.—Since the publication of the second volume of the "Annals" in 1907 a large number of data, obtained by means of the pyrheliometer and the spectrobolometer, have been accumulated and reduced. Observations were made at three stations in addition to Washington, D. C., namely, at Mount Wilson (1,730 meters), Mount Whitney, Cal. (4,420 meters), and near Bassour, Algeria (1,160 meters). The object of the principal investigation was "to determine the intensity of the solar radiation, as it is in free space at the earth's mean solar distance, and to detect variations of the sun's emission if these exceed 1 per cent." The mean value of the solar constant of radiation for the epoch 1902-1912, resulting from 696 observations, was found to be 1.932 calories (15°) per square centimeter per minute. Furthermore, when high values of the solar radiation were observed at Mount Wilson, high values were also found at Bassour and vice versa. "The measurements seem, in fact, to prove conclusively that the radiation of the sun is subject to a variation, occurring irregularly in periods of a week or 10 days, and whose fluctuations are also irregular in magnitude, but usually within the range of 7 per cent." "In addition to this short period variability of the sun, thus disclosed, an intimate association between the intensity of solar radiation and the prevalence of sun spots appears to be strongly indicated". "This relation is such that the greater the number of sun spots the higher is the intensity of the solar radiation". Another important conclusion reached is, "that while the intensities of rays of all wave lengths fall with the decrease of the total solar radiation, the decrease is much more rapid for the shorter wave rays than for the longer".

The appendix (pp. 169-229) contains reprints from the Astrophysical and other journals on the spectroscopic determination of aqueous vapor, the determination of aqueous vapor above Mount Wilson, the sun's energy-spectrum and temperature, the brightness of the sky at night as observed on Mount Whitney, and volcanoes and climate. This very valuable contribution to the subject closes with a list of papers published by members of the observatory staff.

H. S. U.

II. GEOLOGY AND MINERALOGY.

1. *Research in China*. Vol. III. *The Cambrian faunas of China*, by CHARLES D. WALCOTT; *A report on Ordovician fossils collected in eastern Asia in 1903-04*, by STUART WELLER; *A report on Upper Paleozoic fossils collected in China in 1903-04*, by GEORGE H. Girty. Pp. 375; 29 pls., 9 text figs., 1913

(Carnegie Institution of Washington, Publication No. 54).—This long delayed volume completes the great work of Willis and Blackwelder, "Research in China." Our knowledge of the Paleozoic faunas, and especially of those of the Cambrian, is hereby vastly extended. The greater part of volume three is taken up with the Cambrian faunas collected by Iddings and Blackwelder, consisting of 250 forms in 63 genera and 5 subgenera. Of these, 15 forms occur in the Lower Cambrian, 185 in the Middle Cambrian, and 54 in the Upper Cambrian, 4 being common to the Middle and Upper Cambrian.

As is the rule in these early faunas, the Brachiopoda (40 forms), Trilobita (179) and Pteropoda (11) predominate, with the coiled Gastropoda (11) taking their rise. It is stated by the author that "among the brachiopods none of the genera is peculiar to the Chinese Cambrian. All belong to genera found in the Middle Cambrian of western North America and northwestern Europe. . . . The exceptional genera of the Trilobita found in China and not known to occur elsewhere are *Stephanocare*, *Teinistion*, *Blackwelderia*, *Damesella*, and *Drepanura*. All other genera are represented in western North America and western Europe, and there is a striking resemblance even to specific characters in many of the forms. The most noticeable omissions of American and European genera from the Chinese fauna are *Paradoxides* of the Atlantic Basin fauna and *Olenoides*, *Dikelocephalus*, and *Neolenus* of the North American fauna. The closely related genus *Dorypyge* (to *Olenoides*) is found abundantly in China, western United States, and on the island of Bornholm in northwestern Europe. The genera *Ptychoparia*, *Conokephalina*, *Acrocephalites*, *Inouyia*, *Agraulos*, *Lisania*, *Solenopleura*, *Anomocare*, *Anomocarella*, and *Coosia* are well represented in China, western North America, southwestern United States, and northwestern Europe. *Bathyriscus* and *Asaphiscus* are essentially Pacific Basin types" (47, 48).

Walcott summarizes his results as follows :

"The chief results obtained from the study of the Chinese collections are the discovery of portions of the upper part of the Lower Cambrian fauna and a great development of a Middle Cambrian fauna of the same general character as that of the Cordilleran Province of western North America ; also an Upper Cambrian fauna comparable with that of the Cordilleran Province and the Upper Mississippi Province of the United States. . . .

"Another important discovery was that of the occurrence in the Middle Cambrian of China of a fauna comparable with that of the Middle Cambrian of Mount Stephen, British Columbia, and the southern extension of the same fauna in the Middle Cambrian of Idaho, Utah, and Nevada in the United States.

"The determination of the age of the Man-t'o shales [closing epoch of Lower Cambrian time] affords the data by which to fix the period of Cambrian time in which the Cambrian sea transgressed over eastern and southeastern Asia, and shows that it

was somewhat later than the transgression in the Siberian area now occupied by the basins of the Lena and Yenesei rivers" (2).

The Ordovician collections are small but interesting, and consist of 32 forms with many unnamed specifically. Weller concludes:

"The Chinese fauna described in this paper shows clearly its strong relationship with the north European Ordovician faunas, and especially with the fauna of the Glauconite and *Vaginoceras* limestones of the Baltic provinces of Russia. These two formations are essentially equivalents of American faunas included in the Mohawkian division of the Ordovician, and we recognize in this Chinese fauna several species among the brachiopods which are identical with or closely allied to North American Mohawkian forms. The fauna presents in its entirety a mingling of Baltic and North American forms, although the Baltic element is much the more pronounced. In age the fauna is clearly not younger than the Mohawkian faunas of North America, and it may be safely considered as the essential time equivalent of the Black River limestone of North America and of the *Vaginatus* limestone of Russia" (293-4).

The faunas studied by Girty (46 forms) are in the main of Upper Carboniferous time. Regarding them he says:

"The faunas of western North America have, as compared with those of the Mississippi Valley, a distinctly Asiatic facies; but these Chinese faunas are still distinct, the very features which ally them to the faunas of India and China and in which their Asiatic affinities chiefly reside, aiding prominently in showing their alien character to those of even western America" (301-2).

C. S.

2. *Fosseis Devonianos do Paraná*; by JOHN M. CLARKE. Pp. 353, 27 plates, many text figs., 1913. Serviço Geológico e Mineralógico do Brasil, Monographias, Vol. I. In Spanish and English.—With the fullness due to many years' study of the Devonian faunas of North and South America, Doctor Clarke here describes new collections from Brazil, western Argentina, Falkland Islands, and South Africa. Upward of 100 forms, new and old, are discussed and well illustrated. This study has led Clarke to reexamine all of the Lower Devonian faunas of the southern hemisphere and his results are of great import, not only in correlation and faunal assemblages, but as well in paleogeography and the determination of phyletic lines, especially among the trilobites and brachiopods. Of new brachiopod genera there are *Australina*, *Brasilia* and *Derbyina*; of bivalves, *Pleurodapis*; and of trilobites, *Calmonia*, *Pennaia*, *Phacopina*, *Proboloides* and *Schizopyge*.

The austral Lower Devonian faunas are characterized by an abundance of brachiopods, arcoid taxodont bivalves, and trilobites. Capulid gastropods, elsewhere so common at this time, are practically absent, and the same is true of corals, bryozoans and cephalopods. This combination, the author concludes, is

"evidence that the waters in which the assemblage flourished were cool" (26). This evidence also appears to fall in with that of the Table Mountain tillites of South Africa.

"The entire assemblage inclusive of all the Devonian faunas thus far known from Brazil (with exception of the sandstone fauna (Middle Devonian) and black shale fauna (Upper Devonian of Eréré and vicinity); from all horizons in Bolivia, Argentina, the Falkland Islands and Cape Colony (not including the Witteberg series now regarded by some writers as of Carboniferous age) bears a special and distinctive impress which is characterized as *austral* in contrast to the *boreal* aspect of homotaxial faunas north of the equator. These distinctions consist in specific resemblances without identities; in parallel developments affording different resultants; in invasions of generic structures more or less clearly disturbing generic agreements, and in irregular outgrowth of species distinctions on generic foundations common both to the north and the south.

"The fauna discussed . . . shows that the assemblage represents the Early Devonian stages only, and inferentially that in this region later stages of Devonian life and of sedimentation are, on the basis of present knowledge, wholly absent.

"If the foregoing deduction is correct we may infer that the austral continent was either high out of water during the later Devonian, or that the deposits of this time are now deeply submerged under land or sea. We prefer the former conclusion" (7, 8).

"Notwithstanding the faunal distinction north and south, which is essential, there has been no lack of opportunity for the passage of species from the platform of the southern to that of the northern Devonian continent, so closely did the two approach each other both at the east and at the west. And again there has been no departure in the species of the austral fauna from the normal path of development shown by those of the boreal. They have traveled a similar course, building superstructures of unlike detail on a similar foundation. The order of succession in vital events has been harmonious both north and south and as a result there are superficial similarities commingled with more palpable distinctions" (70-1). c. s.

3. *A Monograph of the Terrestrial Palæozoic Arachnida of North America*; by ALEXANDER PETRUNKEVITCH. Trans. Conn. Acad. Arts and Sci., vol. xviii, pp. 1-137, pls. I-XIII, 88 text figs., 1913.—The author here brings together all that is known of North American Paleozoic arachnids. Of specimens he studied 101, and it is not often that an author reaps so rich a harvest, for of the 25 genera treated 13 are new, and of the 42 species, 27 are new. Of the order Solifugæ, no fossil forms were heretofore known, and with one bound the group is now taken back to the Coal Measures in *Protosolpuga carbonaria*. Then there is also defined a new order, Kustarachnæ. The author discusses the system of Arachnida, the phylogenetic development, and the

interrelations of the American and European Carboniferous arachnological faunas.

Now that the foundation has been prepared by a specialist, and one who is a student of living Arachnida as well, American paleontologists can work up the new material as it comes to light. Professor Petrunkevitch is to be congratulated upon his excellent work.

C. S.

4. *The Heart of Gaspé. Sketches in the Gulf of St. Lawrence*; by JOHN MASON CLARKE. Pp. xiv, 292; with many illustrations. New York, 1913 (The Macmillan Company).—It is now thirteen years since Doctor Clarke first visited Gaspé for the purpose of seeing the Lower Devonian formations exposed there. Since then he has been in this secluded land of cod almost every summer, and has fallen deeply in love with the "kindly people of the Gaspé coast" and their picturesque sea-eaten land. In his recent book he presents his "untechnical sketches" of this inviting country in a most sympathetic manner and in captivating language.

Geologists familiar with Clarke's "Early Devonian History of New York and Eastern North America," published in 1908 and 1909, will certainly want to read the present work, not only to learn of the quaint country, but as well to see the author from an interesting viewpoint. Here he is among the fishermen, living with them as their honored guest, learning from them tales of their fisheries, their early settlements, their ancestry, their trials and perils in a bleak land. Throughout there is woven a vivid picture of the scenery, the destructive work of the sea, and something of the geology and natural history. Bonaventure is to him the Isle of the Golden Jug, a trophy that turns him from a hunter of fossils to a seeker of Sunderland ware, a Cartier medallion, and old prints and maps.

"The Heart of Gaspé" is the first book of its kind by an American geologist, and is a reminder of that other happy work, "Mountaineering in the Sierra Nevada," by Clarence King.

C. S.

5. *Ninth Report of the Director of the Science Division*; New York State Mus., Bull. 164. Pp. 214; 50 pls., text figs., 1913.—This report recounts the progress in the various departments of the New York State Museum for the year ending September 30, 1912 (pp. 1-77). Of more special interest are the papers: "The Mount Morris Meteorite," by H. P. Whitlock (78-79); "Early Paleozoic Physiography of the Southern Adirondacks," by W. J. Miller (80-94), in which the relief of the Adirondacks, the times of uplift and the degree of sea encroachment during the Cambrian and Ordovician are stated; "The Garnet Deposits of Warren County, New York," by W. J. Miller (95-102); "The Use of the Stereogram in Paleobiology," by G. H. Hudson (103-131); "The Origin of the Gulf of St. Lawrence" (132-137), "A Notable Trilobite from the Percé Rock" (138-139), and "Illustrations of the Devonian Fossils of

Southern Brazil and the Falkland Islands" (pls. 1-35), by J. M. Clarke. C. S.

6. *New Trilobites from the Maquoketa Beds of Fayette County, Iowa*; by ARTHUR WARE SLOCUM. Field Mus. Nat. Hist., Geol. Ser., IV, No. 3, pp. 43-83, pls. xiii-xviii, 1913.—The author has secured from these beds the large number of 20 species of Richmondian trilobites, 17 of which are here named, 11 of them being new. The new genus *Cybeloides* is also defined. C. S.

7. *A new Paleontologic Periodical—Palaeontologische Zeitschrift*, Bd. I, Heft I, June, 1913.—This is the first number of the organ of the Palaeontologische Gesellschaft of Germany, with Professor Jaekel as editor. Three parts will appear during the year and will be sent free to the members of the Society; otherwise the price is 25 marks per volume. All manuscripts, which may be in German, French, or English, are to be sent to the editor, and subscriptions to the publishers, Gebrüder Borntraeger, W. 35 Schöneberger Ufer 12a, Berlin.

The first paper in this number is by the editor, "Wege und Ziele der Palaeontologie," in which it is said that "the Americans will soon harvest the fruits of the endeavor of the European workers of the past century, and further the progress of our science along its foremost lines." Of other papers there are "Barroisia und die Pharetronenfrage," by H. Rauff (pages 74-144); "Über die palaeontologische Bedeutung des Massensterbens unter den Tieren," by C. Wiman (pages 145-154); and another paper by Jaekel, "Über die Wirbeltierfunde in der oberen Trias von Halberstadt," which is a partial account of the finding of thirty-five dinosaurs and other vertebrates, and which will be continued in the next number.

The Society, which already has 130 German and 80 foreign members, is to be congratulated on its first printed product.

C. S.

8. *Petrology of the alkali-granites and porphyries of Quincy and the Blue Hills, Mass.*; by CHAS. H. WARREN. Proc. Amer. Acad. Arts and Sci., vol. xlix, No. 5, Sept., 1913, pp. 203-330.—While much work has been done on the geology of the Boston basin, none more careful, detailed and thorough on any part of the area, than the one here noticed, has yet been attempted. The alkalic rocks of this region are well known and the complete investigation of this part of them by Professor Warren affords results which are of interest and importance to all petrologists. The field studies show that the rocks are parts of a complex produced by small batholithic invasion whose method of intrusion is believed to have occurred through stoping. The upper portion solidified as vitreous rocks, which give place below to porphyries, while at considerably lower depths granite was produced. The varied relations of these rocks are treated and their petrography, accompanied by chemical analyses, has been worked out in detail. Modern views of physical chemistry are invoked to explain the different textures and mineral constituents met with.

The whole is a valuable contribution and it is to be hoped that Professor Warren may be able to supplement this monograph by further ones dealing with other parts of this region.

L. V. P.

9. *Geology and Ore Deposits of the Philipsburg Quadrangle, Montana*; by WILLIAM H. EMMONS and FRANK C. CALKINS. Pp. 271; 17 pls., 55 figs. U. S. G. S., Prof. Paper, No. 78, 1913.—The Philipsburg Quadrangle is located in central western Montana, only a few miles west of the Butte copper district. The district is one of strong relief ranging in elevation from 4,500 to 10,500 feet. Within the quadrangle lie parts of three mountain masses. The sedimentary rocks of the area range in age from Algonkian to Quaternary and consist largely of limestones and shales, with smaller amounts of sandstones and quartzites. Intrusive igneous rocks occur in large, dome-like masses, and to a less extent in dikes and sheets. The batholithic masses are probably all of Tertiary age. They range in composition from diabase to a siliceous granitoid rock, the more common types being quartz diorite, granodiorite, and granite. The ores of the district are chiefly important for their gold and silver content, although at times copper becomes important. The deposits are of three types and include fissure veins in both igneous and sedimentary rocks, contact-metamorphic replacement deposits in limestone near the granitic intrusions, and replacement deposits in the sedimentary rocks, in part conforming with their bedding planes.

W. E. F.

10. *Gems and Precious Stones in 1912*; by DOUGLAS B. STERRETT. (Adv. chapter, Min. Resources of the United States.)—Dr. Sterrett's annual reports always contain matter of interest to the mineralogist. In the present one he notes the large output of gem sapphires from Montana, from the mines in Fergus County; also the development of opal deposits in Humboldt County, Nevada. These promise to produce gems equal, or perhaps superior, to those of Australia; further, the finding of beautiful amethysts in Warren County, N. C. The diamond localities in Arkansas are spoken of in detail, although the past year has seen no remarkable developments. It is estimated that about 1400 diamonds, weighing nearly 550 carats, were found from August, 1906, to December, 1912. These were valued at \$12,100.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *National Antarctic Expedition, 1901-1904. Meteorology, Part II.* Prepared in the Meteorological Office, under the Superintendence of M. W. CAMPBELL HEPWORTH. London, 1913 (Published by the Royal Society).—Earlier volumes of the National Antarctic Expedition have been from time to time noticed in the pages of this Journal. Part I on Meteorology appeared in 1908 (see vol. xxvi, p. 588). The present volume, Part II, contains a remarkable series of daily synchronous charts extending from October 1,

1901, to March 31, 1904. It gives not only the results of the observations made by the Expedition itself, but also a large number of contemporary observations by other explorers in the Antarctic, by observatories at different points in the southern hemisphere, and by captains of vessels sailing in those seas. The total number of observations charted amounts to nearly 45,000, of which about two-thirds are marine and one-third land observations. We have thus presented a "continuous daily picture of the changing meteorological conditions of the whole Antarctic region south of the 30th parallel of latitude." The charts are given, four on each page, and the larger part give synchronous observations of sea-level pressure for noon, G. M. T., with winds and air temperature. There are also a series of charts of mean sea-level pressure and air temperatures. The records of this expedition gain a peculiar and melancholy interest from the fact that it was led by Capt. Scott, whose last expedition to the same region had so tragic an ending.

2. *Annual Report of the Board of Regents of the Smithsonian Institution, showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1912.* Pp. xii, 780; 72 pls., 11 figs. Washington, 1913.—This volume opens with the report of the Secretary, Dr. CHARLES D. WALCOTT, which has already been noticed in this Journal (see vol. xxxv, p. 200). Pp. 131–780, which follow, include the General Appendix, in which scientific papers by eminent authors in widely different fields are given to the public. The plan in this form has been followed since 1889, although the essential feature involved had been a part of the Annual Report from a very early date. The papers are well chosen and cannot fail of their object to interest and instruct the intelligent general public. Among these may be mentioned a series dealing with the nature and origin of life, including the address to the British Association by Dr. Schäfer; other related papers following deal with the evolution of man by Prof. G. E. Smith, and the history and traditions of human speech. The other departments of science are also well represented.

The explorations and field work of the Smithsonian Institution in 1912 are discussed in detail in a separate pamphlet of 76 pages profusely illustrated (Publication 2178).

3. *Report on the Progress and Condition of the U. S. National Museum for the year ending June 30, 1912.* Pp. 165, Smithsonian Institution. Washington, 1913.—Dr. RATHBUN gives in this volume an extended account of the National Museum, a subject briefly discussed by him in Appendix I to the volume just noticed. It is noted that the acquisitions for the year embrace some 238,000 specimens, more than half belonging to the biological department. It is interesting to remark that on Oct. 8, 1911, the Academy was, for the first time, open to the public on Sunday afternoons; the large number of visitors on these occasions has shown the wisdom of the movement.

Dr. Rathbun has also published, as Bulletin 80 (pp. 125) a descriptive account of the new buildings of the Museum, which being written in considerable detail and with a large number of photographs and detailed plans must be of great value, particularly to those concerned with the construction and administration of museums.

4. *Publications of the British Museum of Natural History*.—The following catalogues have been added recently to the long and valuable series published by the Trustees of the British Museum (see vol. xxxiv, 99 and earlier):

Catalogue of the Plants collected by Mr. and Mrs. P. A. Talbot in the Oban District, South Nigeria, by A. B. RENDLE, E. G. BAKER, H. F. WERNHAM, S. MOORE, and others. Pp. x, 157; 17 pls. These collections were made in 1909–1912. They include 1016 species and varieties, 195 of which are new; there are also nine new genera. The district adjoins the Cameroons and botanically is an extension of the evergreen rain-forest area, the flora being practically identical with that of the Cameroons.

Catalogue of the Lepidoptera Phalaenæ in the British Museum, Vol. XII, Plates CXCI–CCXXI.

Catalogue of the Ungulate Mammals in the British Museum. Vol. I. Artiodactyla, Family Bovidae, Subfamilies Bovinæ to Ovibovinæ (Cattle, Sheep, Goats, Chamois, Serows, Takin, Musk-Oxen, etc.); by R. LYDEKKER. Pp. xvii, 249; 55 figs. Forty years have passed since the last catalogue of ungulate mammals was published; it is not surprising, therefore, that the Museum collections during this period have enormously increased.

Catalogue of the Books, Manuscripts, Maps and Drawings in the British Museum (Natural History), Vol. IV, P–SN. Pp. 1495–1956, 410.

5. *Publications of the Museum of the Brooklyn Institute of Arts and Sciences*.—The following have recently been issued:

Science Bulletin, Vol. II, No. 1. Long Island Fauna and Flora, I. The Bats; by ROBERT CUSHMAN MURPHY and JOHN TREADWELL NICHOLS. Pp. 15. No. 2. Long Island Fauna and Flora, II. A Long Island Acmea, and a new variety of *Urosalpinx linerea*; by SILAS C. WHEAT. Pp. 17–20; 1 pl.

6. *National Academy of Sciences*.—The regular autumn meeting of the National Academy met in Baltimore on November 18–20. The following is the list of papers presented:

H. F. OSBORN: Final results on the phylogeny or lines of descent in the Titanotheres.

T. H. MORGAN: The constitution of the chromosomes as indicated by the heredity of linked characters.

H. McL. EVANS: The action of vital stains belonging to the benzidine group.

S. O. MAST: Changes in pattern and color in fishes, with special reference to flounders.

D. S. JOHNSON: The perennating fruits of the prickly pears.

B. F. LOVELACE: A static method for the measurement of vapor-pressures of solutions.

H. C. JONES: The absorption of light by water containing strongly hydrated salts.

A. G. WEBSTER: The transmission of sound through porous materials. A new portable phonometer.

SIMON FLEXNER: Factors in the epidemiology of infection.

KNIGHT DUNLAP: The fusion of successive flashes of light.

L. B. MENDEL: Factors relating to the rôle of the inorganic components of the diet.

H. A. KELLY: Radio-therapeutics in surgical affections.

A. H. PFUND: Measurement of stellar radiation.

J. A. ANDERSON: A method for testing screws.

J. B. WATSON: An experimental study of homing.

G. F. BECKER and A. L. DAY: Fresh experiments on the linear force of growing crystals.

L. V. KING: Phonometric characteristics of fog-signal equipment.

H. F. REID: Sea waves due to earthquakes.

C. B. DAVENPORT: Absence of correlation between curliness of the hair and color of the skin in offspring of negro-white crosses.

S. WEIR MITCHELL: Biographical memoir of Dr. John S. Billings.

7. *The Elements of Bacteriological Technique*; by J. W. H. EYRE, M.D., Director of the Bacteriological Department of Guy's Hospital, London. Second edition. Pp. 518, 219 illustrations. Philadelphia and London (W. B. Saunders Company), 1913.—Since the first edition of this work appeared (1903) much has been added to our knowledge of bacteria in their various relationships. The new edition contains a great deal that is not found in the old. This is most apparent in the description of methods employed in serological work. Furthermore, numerous valuable illustrations have been added.

Bacteriological technique is new, even to the student of botany, zoology or chemistry. For this reason, and on account of the numerous methods involved, it is necessary for the student to receive almost constant help from the instructor, or with the aid of a satisfactory written guide. The present edition is comprehensive and clear. The subject matter is divided into 21 chapters, altogether covering the field of general bacteriological technique admirably. It is not intended so much for advanced students, or investigators, as for those who are endeavoring to acquire a general thorough knowledge of bacteriological and bio-chemical technique as an essential in the study of bacteria themselves. The book is planned as a laboratory guide for the technical student generally, whether he is particularly interested in preventative or curative medicine, brewing, dairying or agriculture.

L. F. R.

OBITUARY.

ALFRED RUSSELL WALLACE, the veteran English naturalist and traveler, died on November 7 in his ninety-first year. His contributions to science were numerous, varied and of the first importance, but his name will be chiefly remembered because of his prominent share in the building up of the theory of evolution.

Sir WILLIAM HENRY PREECE, who contributed largely to the development of the telegraph and telephone in Great Britain, died on November 6 in his eightieth year.

INDEX TO VOLUME XXXVI.*

A

- Academy**, National, History of the first half century, 185.
 — Baltimore meeting, 658.
Alabama geol. survey, 79.
Allegheny Observatory, 89.
Antarctic Expedition, National, Meteorology, Pt. II, 657.
Astrophysical Observatory, Annals, 650.
Atom, Beyond the, Cox, 566.
Atwood, E. L., Modern Warship, 314.
Aurora Borealis, spectrum, Vegard, 646.

B

- Bacteriological Technique**, Eyre, 659.
Barrell, J., Upper Devonian delta of the Appalachian geosyncline, 429.
Bermuda, deep boring, Pirsson and Vaughan, 70.
Bingham, H., supposed prehistoric human remains of Cuzco, 1.
Black, N. H., Physics, 566.
Blackwelder, E., Paleozoic faunas of Wyoming, 174.
Blake, J. C., General Chemistry, 563.
Bolivia, La Paz gorge, Gregory, 141.
Borings, deep, Bermuda, 70; Findlay, O., 123, 131; near Copenhagen, 313.
Bradley, W. M., composition of albite, 47; pyroxmangite, 169; composition of chrysocolla, 180.
British Museum, catalogues, 84, 658.
Brooklyn Institute, publications, 658.
Browning, P. E., preparation of telluric acid, 72; preparation of tellurous acid, 399.
Buchanan, J. Y., specific gravity, etc., of some saline solutions, 421.
Bumstead, H. A., velocities of delta rays, 91.

C

- Canada**, banded gneises of Laurentian highlands, Wilson, 109
 — Department of Mines, 79.
Cape of Good Hope, annual report of Geological Commission, 568.
Carnegie Institution, publications, 575.
Carothers Observatory, 89.
Chemical Analysis, Rockwood, 74; Qualitative, Noyes, 418.

- Chemical German**, Phillips, 646.
 — News, General Index, 87.
Chemie, Physikalische, etc., Jellinek, 567.
Chemistry, Kahlenberg and Hart, 564.
 — Applied, Dictionary of, Thorpe, vol. IV, 563.
 — General, Blake, 563; Smith and Keller, 646.
 — New Era, Jones, 645.
 — Organic, Molinari, 563.
 — Physiological, Hawk, 75.

CHEMISTRY.

- Alcohol and sugar cane, influence upon solution of cadmium, Van Name and Hill, 543.
 Beryllium, metallic, Fichter and Jablezynski, 562.
 Boron, hydrides, Stock, 562.
 Bromine, detection, Guareschi, 416.
 Calcium hydride, Moldenhauer and Roll-Hansen, 417.
 Carbon, new oxide, Meyer and Steiner, 73.
 Fluorine, Greef, 645.
 Hydrogen, behavior towards palladium, Gutbier, etc., 645.
 Iron, etc., heat of combustion of oxides, etc., Mixer, 55.
 Manganese, volatile oxide, Lank-shear, 416.
 Per- Acids and Salts, Price, 75.
 Silica, dehydration and recovery, Gooch, Reckert and Kuzirian, 598.
 Sodium paratungstate, Kuzirian, action of, 301; use of, 305.
 Steels, analysis of special, Zinberg, 417.
 Sulphates, water of crystallization in, Kuzirian, 401.
 Sulphur trioxide, action upon salts, Traube, 644.
 Telluric acid, preparation, Browning and Minnig, 72.
 Tellurous acid, preparation, Oberhelman and Browning, 399.
 Tungsten compounds, Olsson, 73.
China, Research in, Walcott, 650.
Clarke, J. M., The earth of Gaspé, 654; Fosseis Devonianos do Paraná, 650.
Coal, Mine Explosions, Harger, 81.
Coast Survey, U. S., report, 87.
Cockerell, T. D A., fauna of the Florissant shales, 498.
Colorado, fossil Coleoptera, Wickham, 83.

*This Index contains the general heads, CHEMISTRY, GEOLOGY, MINERALS, OBITUARY, ROCKS; under each the titles of Articles referring thereto are included.

- Condit, D. D.**, deep wells at Findlay, Ohio, 123.
Cordeiro, F. J. B., Gyroscope, 647.
Cox, J., Beyond the Atom, 566.
Crawford, R. D., geology of the Monarch district, Colorado, 82.
Crystal Atlas, Goldschmidt, 313.
Crystals, model to show symmetry of, Phillips, 80.
Cuzco, see Peru.

D

- Dale, T. N.**, Ordovician outlier, Sudbury, Vermont, 395.
Davis, H. N., Physics, 566.
Delta rays, velocities, Bumstead, 91.
Dennis, L. M., Gas Analysis, 74.
Derby, O. A., stem structure of *Psaronius brasiliensis*, 489.
Detroit Observatory, 89.
Duncan, J. Mechanics and Heat, 565.

E

- Eaton, G. F.**, vertebrate remains in the Cuzco gravels, 3.
Ecology, Journal of, 87.
Eggs, bacteria in, Kossowicz, 88.
Electrons, see Delta rays.

F

- Farwell, H. W.**, optical bench for elementary work, 473.
Feldspars, plagioclase, graphical plot for, Wright, 541.
Fenner, C. N., stability relations of silica minerals, 331.
Field Museum, Chicago, annual report, 86.
Findlay, Ohio, deep wells, geology, Condit, 123; temperature, Johnston, 131.
Finlay, G. I., Igneous Rocks, 573.
Fischer, O., Medizinische Physik, 648.
Fleming, J. A., Wireless Telegraphy, 648.
Florissant shales, fauna of, Cockerell, 498.
Foot, H. W., composition of albite, 47; of chrysocolla, 180.
Ford, W. E., pyroxmangite, 169.

G

- Gale, H. G.**, Physics, 423.
Gamma rays, interference, Shaw, 420.
Gas Analysis, Dennis, 74.
Gaspé, Heart of, Clarke, 654.
Gauss, Biography, Klein and Brendel, 423.

GEOLOGICAL REPORTS.

- Alabama, 79.
 Cape of Good Hope, 568.
 Colorado, 82.

GEOLOGICAL REPORTS.

- New Jersey, 78.
 New Zealand, 569.
 Ohio, 80.
 United States, Publications, 77, 424.
 Vermont, 425.
 Virginia, 80, 568.
 Western Australia, 569.
 West Virginia, 79.
 Wisconsin, 79.
 Wyoming, 81.

GEOLOGY.

- Arachnida, Paleozoic, of No. America, Petrunkevitch, 653.
 Cambrian Faunas in China, Walcott, 650.
 Carboniferous and Devonian, unconformity between, Keyes, 160.
 Coleoptera, fossil, Colorado, Wickham, 83.
 Cretaceous deposits of Miyako, 425.
 Devonian faunas of South America, etc., Clarke, 650.
 — formation, Ohio, Prosser, 82.
 — fossiliferous horizon at Littleton, N. H., Lahee, 231.
 — Upper, delta of the Appalachian geosyncline, Barrell, 429.
 Eurypterids of Kokomo, Ind., age, Kindle, 282.
 Fauna of the Florissant shales, Cockerell, 498.
 Geology and ore deposits of Philipsburg Quadrangle, Montana, Emons and Calkins, 656.
 LaPaz gorge, Bolivia, Gregory, 141.
 Laurentian highlands, banded gneisses of, Wilson, 109.
 Liassic flora of Mexico, Wieland, 251.
 Lower Siluric of Mohawk Valley, shales, Ruedemann, 83.
 Ordovician fossils in Eastern Asia, Weller, 650.
 — outlier, Sudbury, Vt., Dale, 395.
 Paleozoic faunas of Wyoming, Blackwelder, 174.
 — section in Utah, Richardson, 406.
 — Upper, fossils in China, Girty, 650.
Psaronius brasiliensis, Derby, 489.
 Trilobites from Iowa, Slocum, 655.
 Tropidoleptus zones of New York Devonian, Williams, 571.
 Vertebrate remains from Cuzco, Peru, Eaton, 3.
 Geophysical Laboratory, papers from, 131, 331, 509, 540, 577.
Goldschmidt, V., Atlas der Krystallformen, Vol. I, 313.
Gooch, F. A., dehydration and recovery of silica, 598.
Graham, R. P. D., crystallization of willemite, 639.

Gregory, H. E., gravels at Cuzco, 15; La Paz (Bolivia) gorge, 141; geologic sketch of Titicaca Island, 187.

Gyroscope, Cordeiro, 647.

H

Heat of formation of oxides of iron, etc., Mixer, 55.

Hess, F. L., triplite, Nevada, 51.

Hill, D. W., influence of alcohol and sugar cane upon solution of cadmium, 543.

Hornor, N. N., sealing wax as a source of lime for Wehnelt cathode, 591.

Hunt, W. F., triplite, Nevada, 51; vanadiferous ægirites from Montana, 289.

Hurricanes, West Indian, Fassig, 88.

Hutchins, C. C., quartz spectrograph, 328.

I

Iddings, J. P., Igneous Rocks, 571.

Illinois, Waters of, chemical survey, Bartow, 90.

Iodine, new fluorescence spectrum, McLennan, 418.

Ionization, columnar, Wellisch and Woodrow, 214.

Italian Seas, publication of Commission on, 88.

J

Jellinek, K., Physikalische Chemie, etc., 567.

Johnston, J., temperature in deep wells, Findlay, Ohio, 131.

Jones, H. C., New Era in Chemistry, 645.

K

Keller, H. F., General Chemistry, 646.

Keller, O., die antike Tierwelt, 426.

Keyes, C. R., unconformity between upper Mississippi Carboniferous and Devonian, 160.

Kilauea, formations of, Perret, 151; volcanic research, Perret, 475.

Kindle, E. M., age of Eurypterids of Kokomo, Ind., 282.

Krystall formen, Atlas, Vol. I, Goldschmidt, 313.

Kuzirian, S. B., sodium paratungstate, action of, 301; use of, 305; water of crystallization in sulphates, 401; dehydration and recovery of silica, 598.

L

Lahee, F. H., new fossiliferous horizon, Littleton, N. H., 231.

Larsen, E. S., vanadiferous ægirites from Montana, 289; custerite, 385.

Lava, ascent of, Perret, 605.

Lavas from Sardinia, Washington, 577.

Littleton, N. H., new fossiliferous horizon, Lahee, 231.

Lulham, R., Zoology, 84.

M

Magnetic phenomena in rods due to twist, Williams, 555.

Magneto-Optics, Zeeman, 565.

Malaria, Herms, 84.

Mechanics and Heat, Duncan, 565.

Mennell, F. P., Petrology, 446.

Meteorite, iron, Paulding County, Georgia, Watson, 165.

Mexico, Liassic flora, Wieland, 251.

Millikan, R. A., Physics, 423.

Minerals, silica, stability relations of, Fenner, 331.

— solid solution in, Foote and Bradley, 47, 180.

MINERALS.

Ægirites, vanadiferous, 289. Albite, 47.

Chalcedony, 379. Chrysocolla, composition, 180. Crystobalite, 334, 343, etc. Cuprodescliozite, new, 636. Custerite, Idaho, new, 385.

Plattnerite, Idaho, 427. Pyroxmangite, So. Carolina, new, 169.

Quartz, 334, 349, etc.

Skemmatite, So. Carolina, new, 169.

Tridymite, 334, 343, etc. Triplite, Nevada, 51.

Willemite, crystallization, 639.

Mines, U. S. Bureau of, publications, 78.

— Department of, Canada, 79; New Zealand, 81.

Mining World Index, 90, 576.

Minnig, H. D., preparation of telluric acid, 72.

Mixer, W. G., heat of formation of oxides of iron, etc., 55.

Miyako, Cretaceous deposits, 425.

Molinari, E., Organic Chemistry, 563.

Müller's Serodagnostic Methods, Whitman, 428.

N

National Museum, United States, report, 658.

New Jersey geol. survey, 78.

New York State Museum, report of Science Division, 654.

New Zealand, Dept. of Mines, 81; geol. survey, 569.

Noyes, A. A., Qualitative Chemical Analysis, 418.

O

Oberhelman, G. O., preparation of tellurous acid, 399.

OBITUARY.

Avebury, Lord, 90.

Credner, H., 576.

Eastman, J. R., 576.

Hallock, W., 90. Hartley, W. N., 576. Holzapfel, E., 186.

Kittl, E., 90.

Laspeyres, H., 576.

MacFarlane, A., 576. Macgregor, J. G., 90. Marshall, H., 576. Milne, J., 576.

Preece, W. H., 659.

Rockwood, C. R., 576.

Selater, P. L., 576.

Wallace, A. R., 659.

Weber, H., 576.

Observatory, Allegheny, 89; Astrophysical, 650; Carothers, 89; Detroit, 89.

Ohio, Devonian formation, Prosser, 82.

— geol. survey, 80.

Optical bench, Farwell, 473.

Optics, Geometrical, Southall, 649.

Ore deposits of Philipsburg, Mont., Emmons and Calkins, 656.

P

Pacinotti, A., *Macchinetta Elettromagnetica*, 424.

Page, L., photoelectric effect, 501.

Palache, C., crystallization of willemite, 639.

Paleontology, new periodical, 655.

Patterson, R. A., arc spectrum of tellurium, 135.

Perret, F. A., Kilauean formations, 151; vertical motion seismographs, 297; volcanic research at Kilauea, 475; ascent of lava, 605.

Peru, Yale Expedition, supposed prehistoric human remains, Bingham, 1; vertebrate remains, Eaton, 3; gravels at Cuzco, Gregory, 15; see also 141, 187.

Petrography, microscopical, Wright, 509.

Petrology, Mennell, 426; of the Blue Hills, Mass., Warren, 655.

Phillips, A. H., model to show symmetry of crystals, 30.

Phillips, F. C., *Chemical German*, 646.

Photochemical Investigations, Plotnikow, 422.

Photoelectric effect, Page, 501.

Physical measurements, Duff and Ewell, 649.

Physics, Millikan and Gale, 423.

— Practical, Black and Davis, 566.

Physik, Medizinische, Fischer, 648.

Pirsson, L. V., deep boring in Bermuda, 70.

Planetologia, Cortese, 428.

R

Radiation, solar, Very, 609.

Radium, active deposit in an electric field, Wellisch, 315.

Rays, see **Delta rays**, **Gamma rays**.

Reckert, F. C., dehydration and recovery of silica, 598.

Richardson, G. B., Paleozoic section in northern Utah, 406.

Ries, C., electric properties of selenium, 422.

ROCKS.

Alkali-granites and porphyries of Blue Hills, Mass., Warren, 655.

Alkaline rocks, composition and origin, Smyth, 33.

Gneisses of Laurentian highlands, Canada, Wilson, 109.

Igneous Rocks, Iddings, 57; Finlay, 573.

Lavas from Monte Arci, Sardinia, Washington, 577.

Rhyolites, trachytes, etc., Sardinia, Washington, 577.

Rockwood, E. W., *Chemical Analysis*, 74.

Rubidium rays, deviation, Bergwitz, 564.

S

Salts, dissolved, influence on absorption bands of water, Jones, Guy and Shaeffer, 76.

Sardinia, lavas from Monte Arci, Washington, 577.

Schaller, W. T., custerite, 385.

Sealing wax as source of lime for Wehnelt cathode, Hornor.

Seismographs, vertical motion, Perret, 297.

Selenium, electric properties, Ries, 422.

Semon, R., die Vererbung "Erworbener Eigenschaften," 314.

Shannon, E. V., plattnerite in Idaho, 427.

Silica, minerals, stability relations of, Fenner, 331.

Smith, E. F., *Chemistry*, 646.

Smithsonian Institution, annual report, 658.

Smyth, C. H., Jr., composition and origin of alkaline rocks, 33.

Solar radiation, Very, 609.

Southall, J. P. C., *Geometrical Optics*, 649.

Spectrograph, quartz, Hutchins, 328.

Specific Gravity of Saline Solutions, etc., Buchanan, 421.

- Spectrum**, aurora borealis, 646;
iodine, 418.
— tellurium, Uhler and Patterson,
135.
— in the ultra-violet, Henri, 647.
Steel rods, twist in. due to a mag-
netic field, Williams, 555.
Sterrett, D. B., Gems in 1912, 656.

T

- Taschenberg, O.**, Bibliotheca Zoo-
logica, 89.
Tellurium, arc spectrum, Uhler and
Patterson, 135.
Thorpe, E., Dictionary of Applied
Chemistry, vol. IV, 563.
Thresh, J. C., Examination of Waters
and Water Supplies, 74.
Tierwelt, die antike, Keller, 426.
Titicaca Island, geologic sketch,
Gregory, 187.
Tornquist, work on geotectonics, 571.

U

- Uhler, H. S.**, arc spectrum of tellu-
rium, 135.
Umpleby, J. B., eusterite, 385.
United States Bureau of Mines, 78.
— Coast Survey, 87.
— Geol. Survey, 77, 424.
— National Museum, report, 657.
Uranium X₂, a new element, Fajans
and Göhring, 565.
Utah, Paleozoic section in, Richard-
son, 406.

V

- Valency**, Loring, 564.
Van Name, R. G., influence of alco-
hol and sugar cane upon solution of
cadmium, 543.
Vaughan, T. W., deep boring in
Bermuda, 70.
Vermont, Geology and Mineral In-
dustries, Perkins, 425.
— Sudbury, Ordovician outlier, Dale,
395.
Very, F. W., solar radiation, 609.
Virginia geol. survey, 80, 568.
Volcanoes, see Kilauea.
Vulcanismus, von Wolff, 574.

W

- Walcott, C. D.**, Research in China,
650.

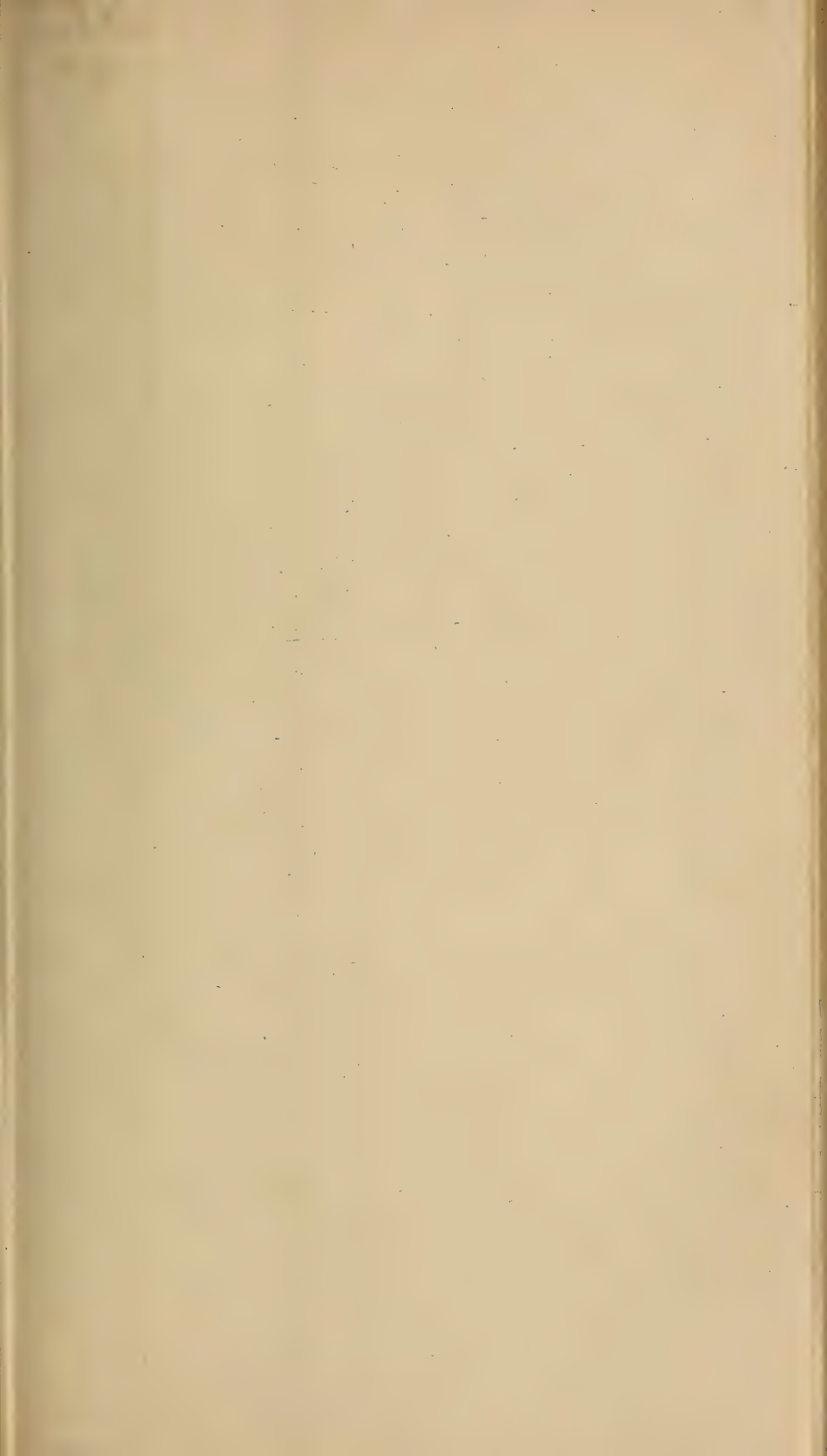
- Warren, C. H.**, petrology of Quincy
and Blue Hills, Mass., 655.
Warship, Modern, Atwood, 314.
Washington, H. S., lavas from
Monte Arci, Sardinia, 577.
Water, absorption bands of, 76.
Waters, Examination of, Thresh, 74.
Watson, T. L., meteoric iron from
Paulding county, Georgia, 165.
Wehnelt cathode, sealing wax as
source of lime, Hornor, 591.
Wellisch, E. M., columnar ioniza-
tion, 214; active deposit of radium
in an electric field, 315.
Wells, deep, at Findlay, Ohio, geol-
ogy, Condit, 123; temperature,
Johnston, 131.
Wells, R. C., new occurrence of
cuprodesclowitzite, 636.
West Indies, Hurricanes, Fassig, 88.
West Virginia geol. survey, 79;
geol. map, 79.
Western Australia geol. survey,
569.
Whitman, R. C., Müller's Serodiag-
nostic Methods, 428.
Wieland, G. R., Liassic floras of
Mexico, 251.
Williams, H. S., Tropicodileptus
zones in New York, 571.
Williams, S. R., twist in steel and
nickel rods due to a magnetic field,
555.
Wilson, M. E., banded gneisses of
Laurentian highlands, 109.
Wireless Telegraphy, Fleming, 648.
Wisconsin geol. survey, 79.
Woodrow, J. W., columnar ioniza-
tion, 214.
Wright, F. E., graphical methods
of microscopical petrography, 509;
graphical plot for the plagioclase
feldspars, 541.
Wyoming geol. survey, 81.

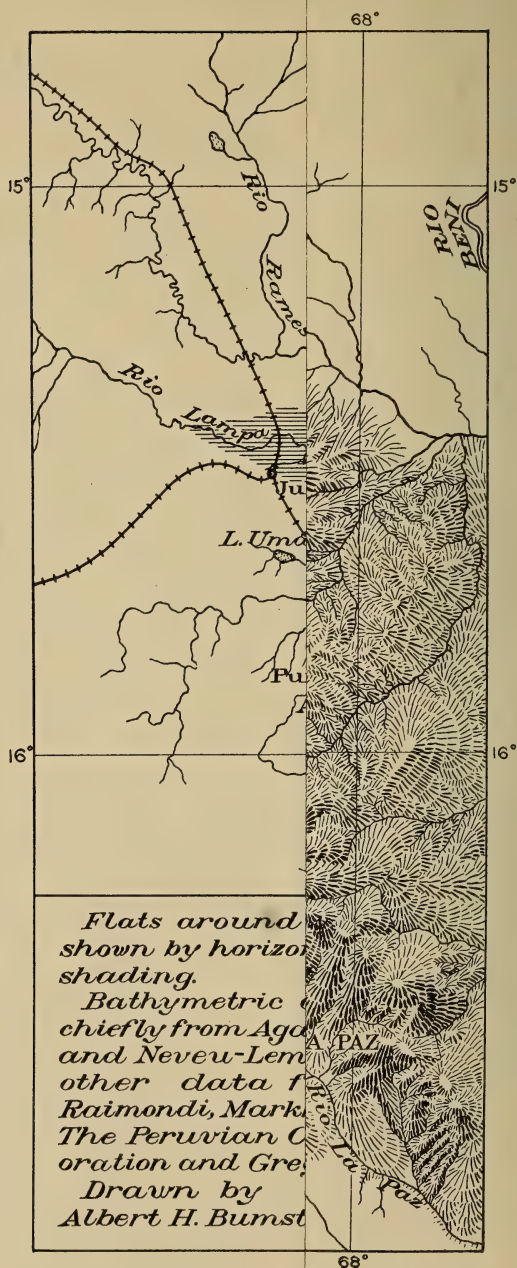
Y

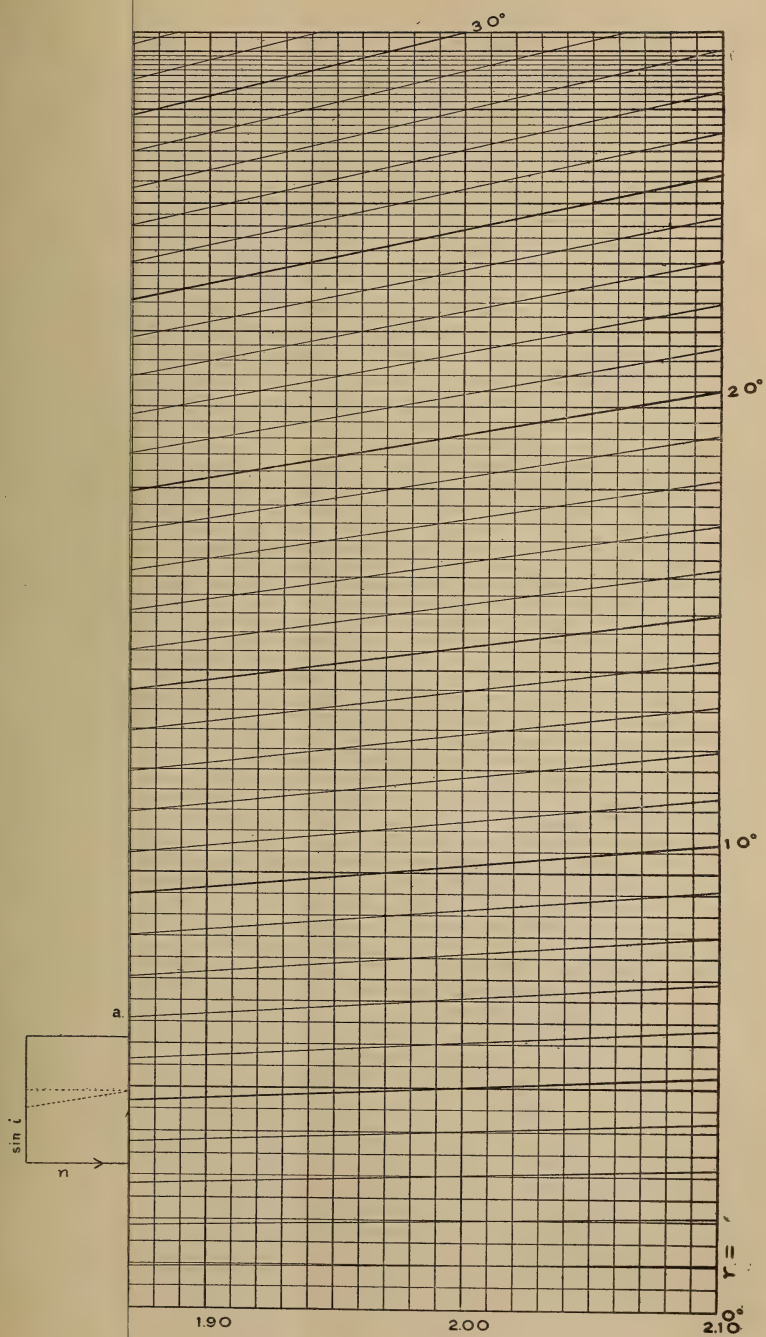
- Yale Peruvian Expedition**, results of,
Bingham, 1; Eaton, 3; Gregory,
15, 141, 187.

Z

- Zeeman, P.**, Magneto-Optics, 565.
Zoologica, Bibliotheca, II, Taschen-
berg, 89.
Zoology, Daugherty, 314; Lulham,
84.



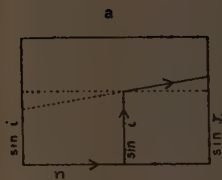


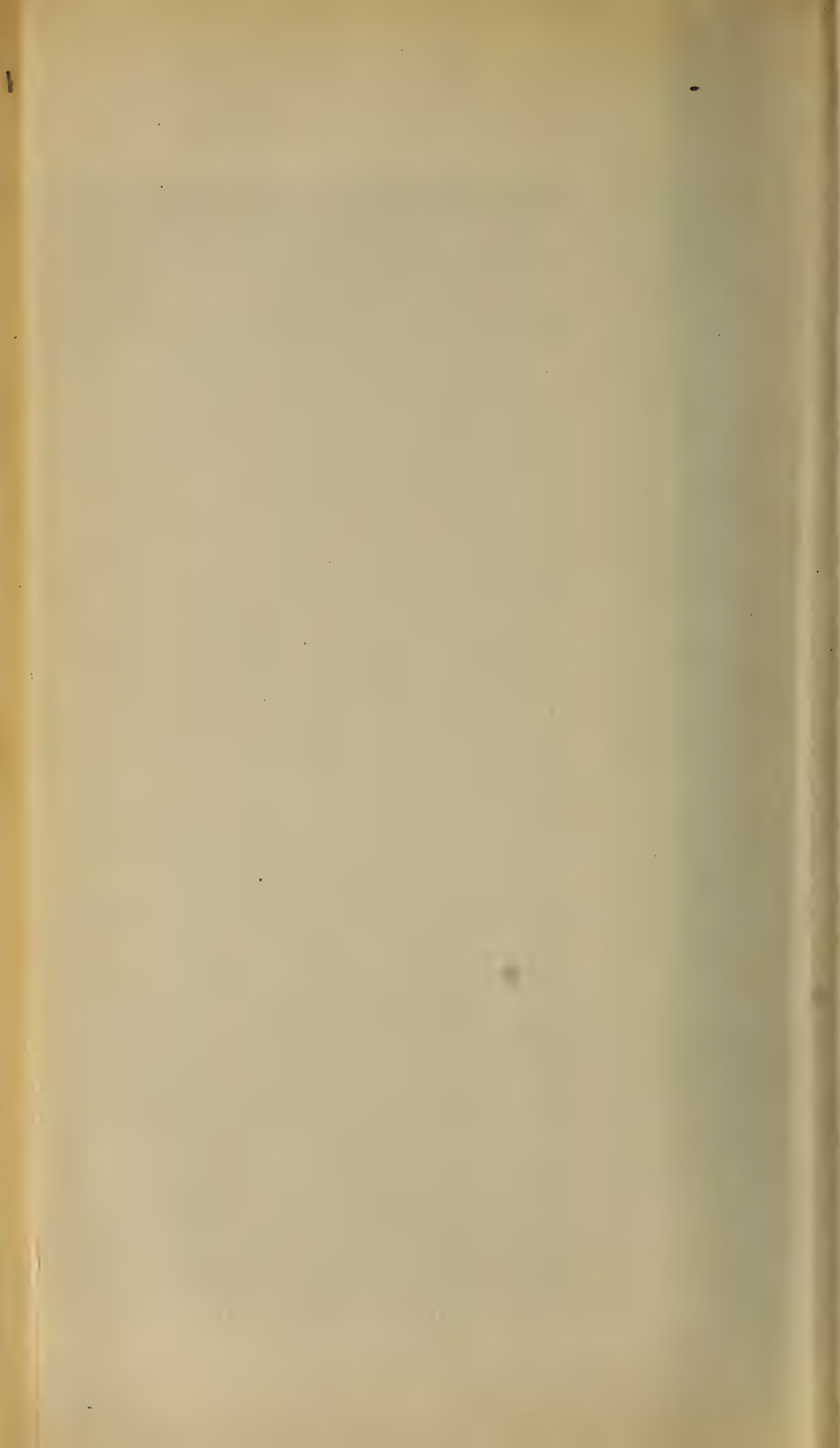


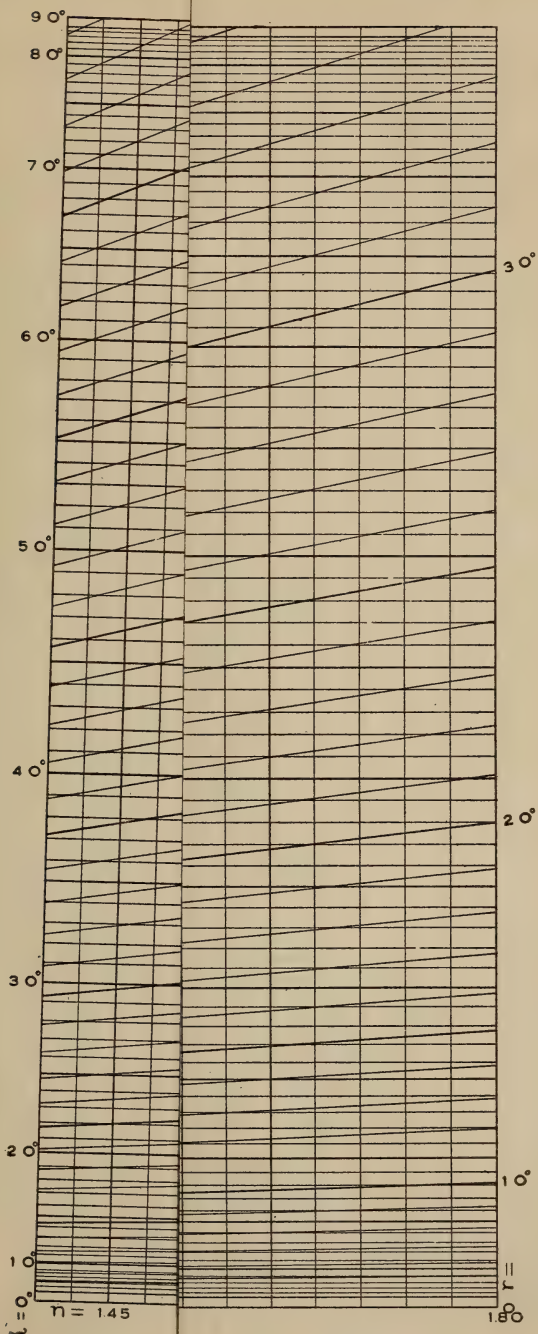
THE PERUVIAN EXPEDITION OF 1912
 UNDER THE AUSPICES OF
 YALE UNIVERSITY & THE NATIONAL GEOGRAPHIC SOCIETY
 HIRAM BINGHAM, DIRECTOR

LAKE TITICACA & VICINITY

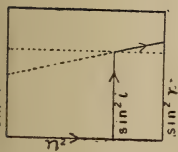


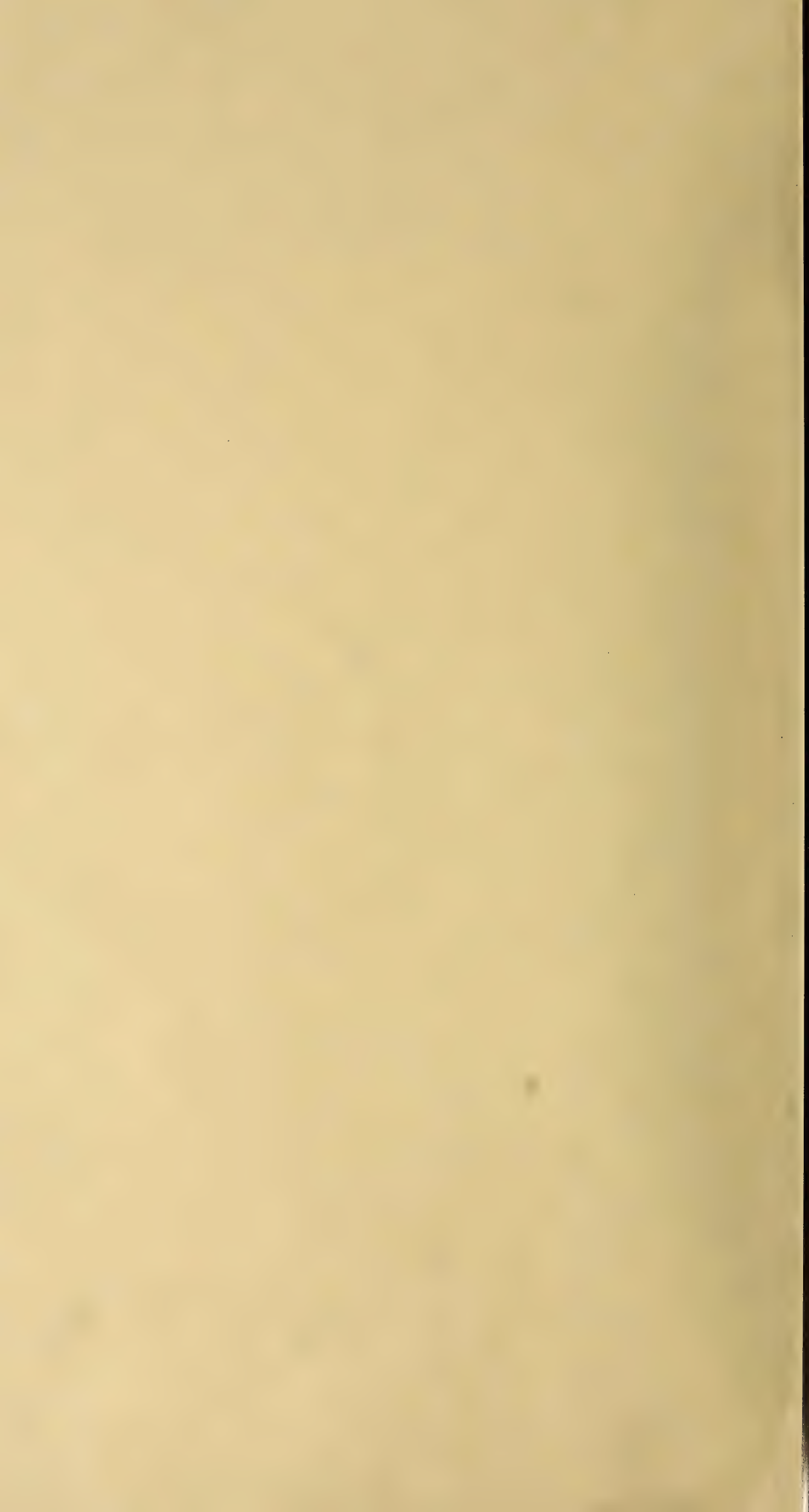


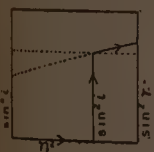
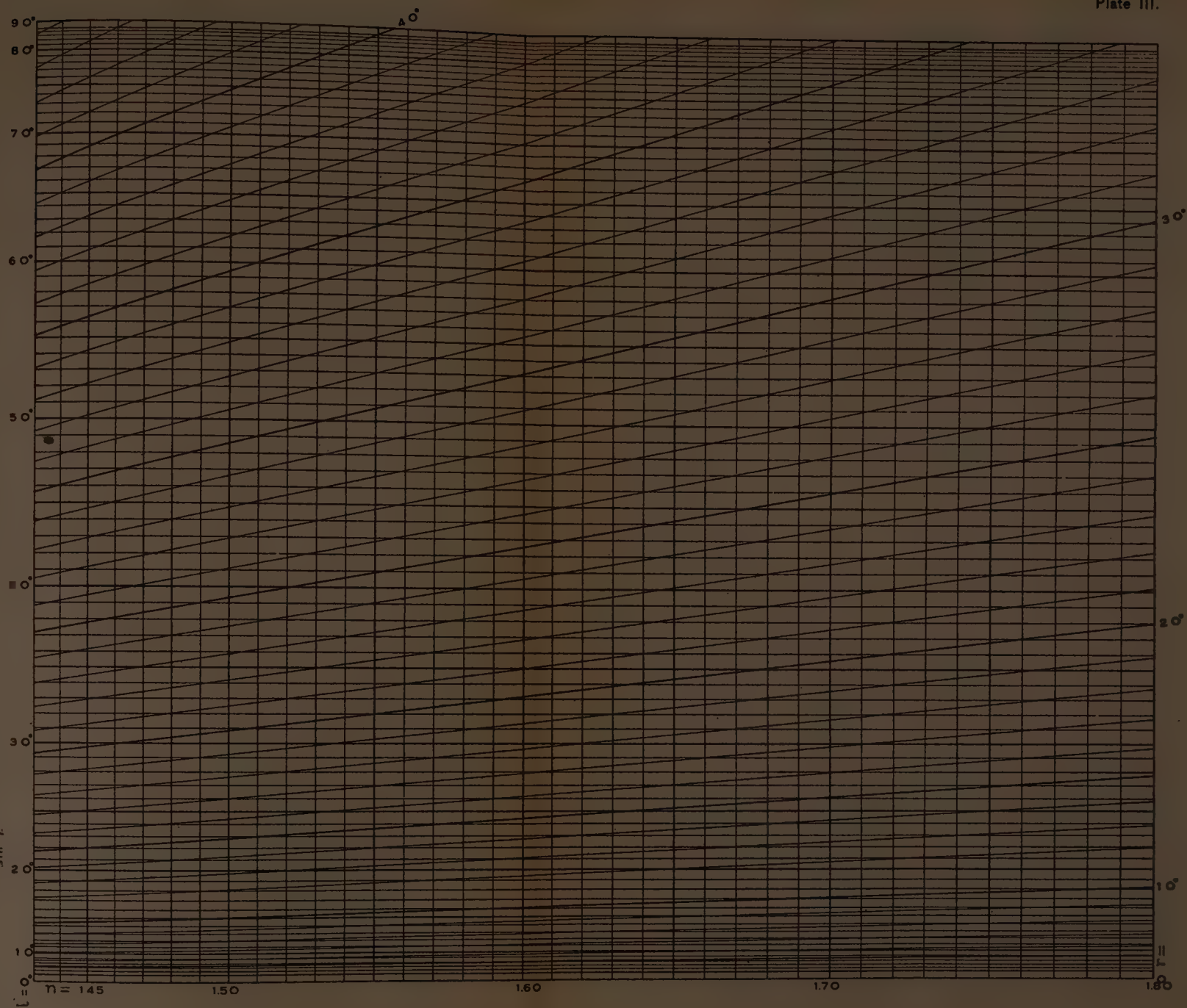




a.



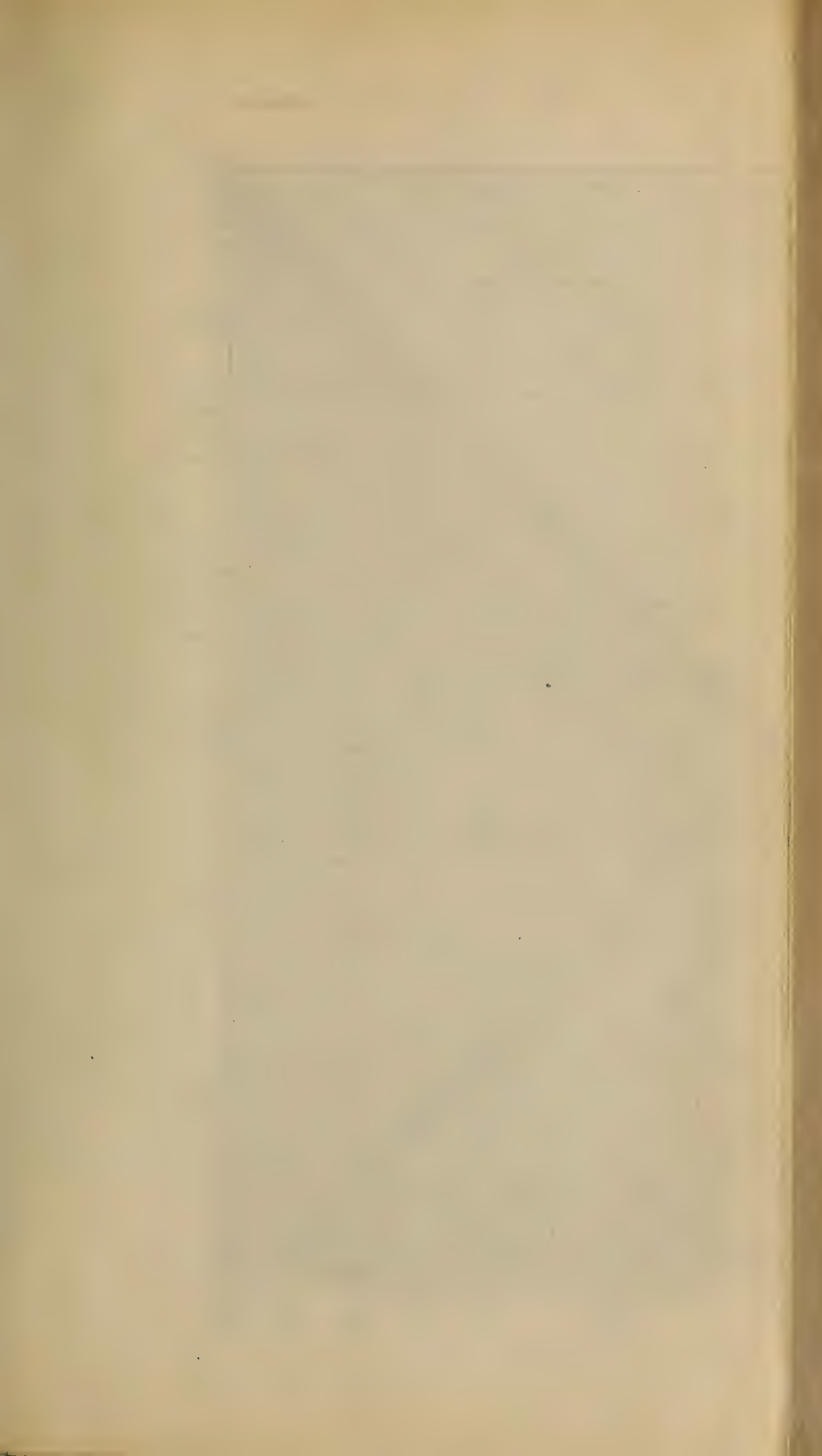


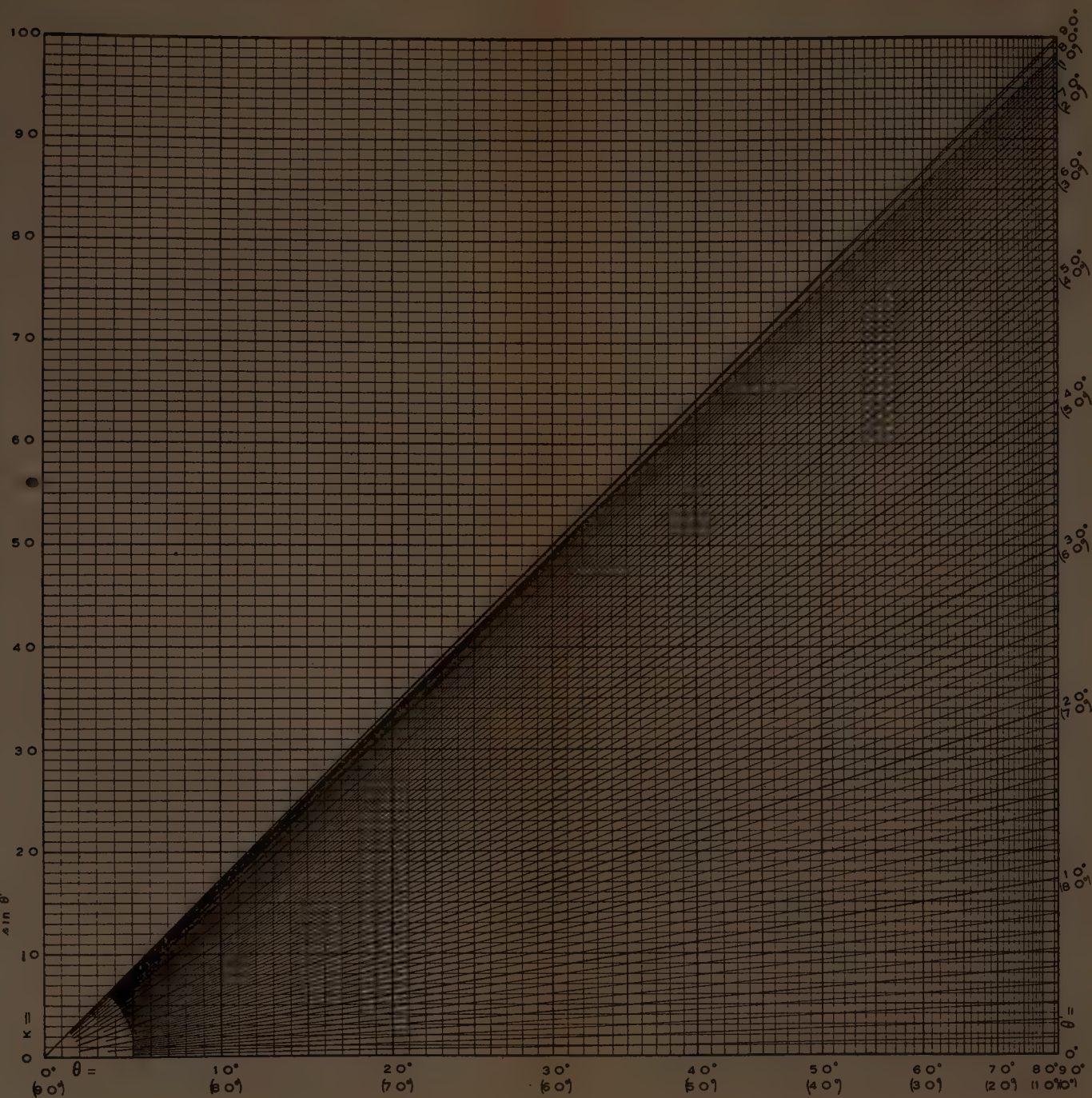




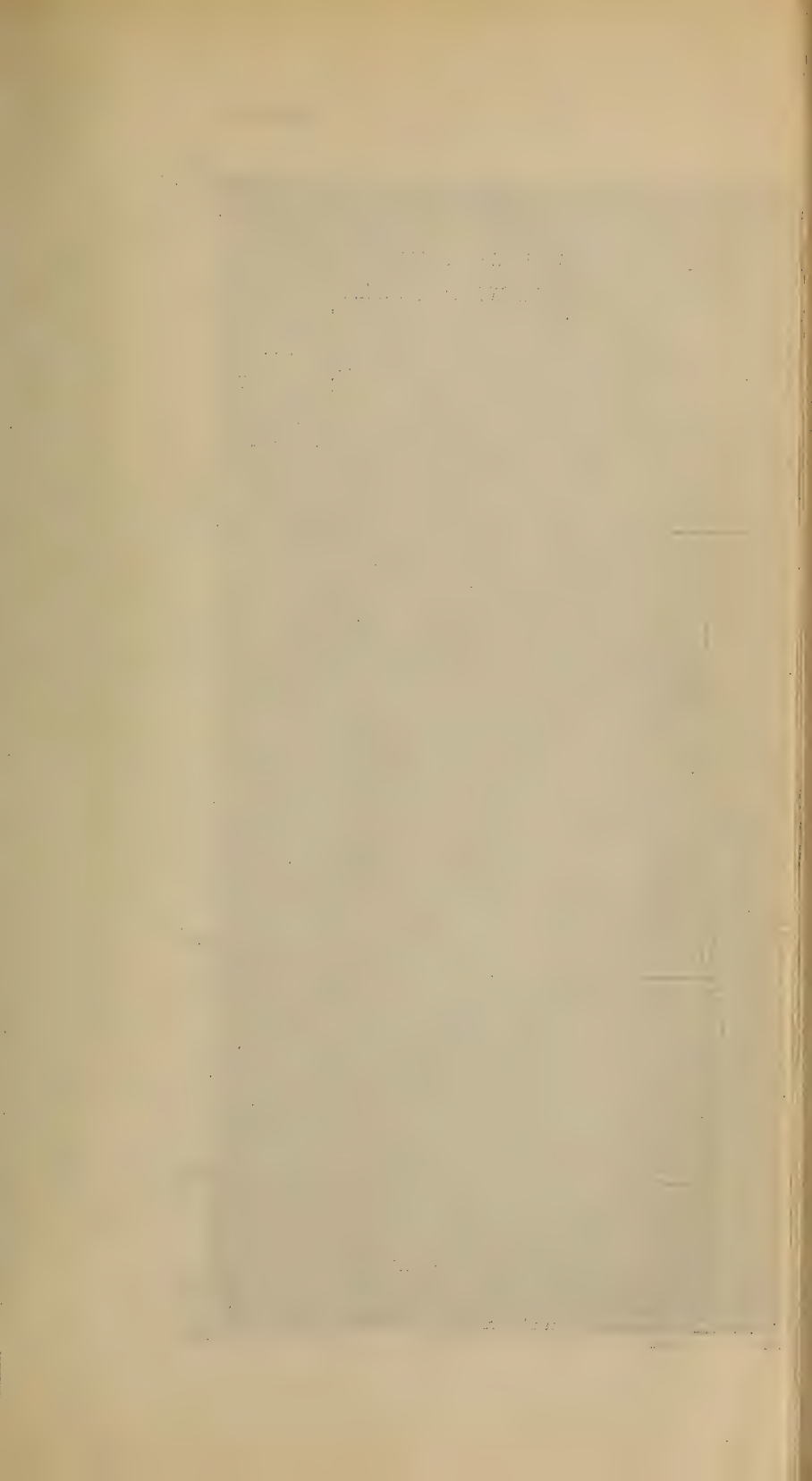


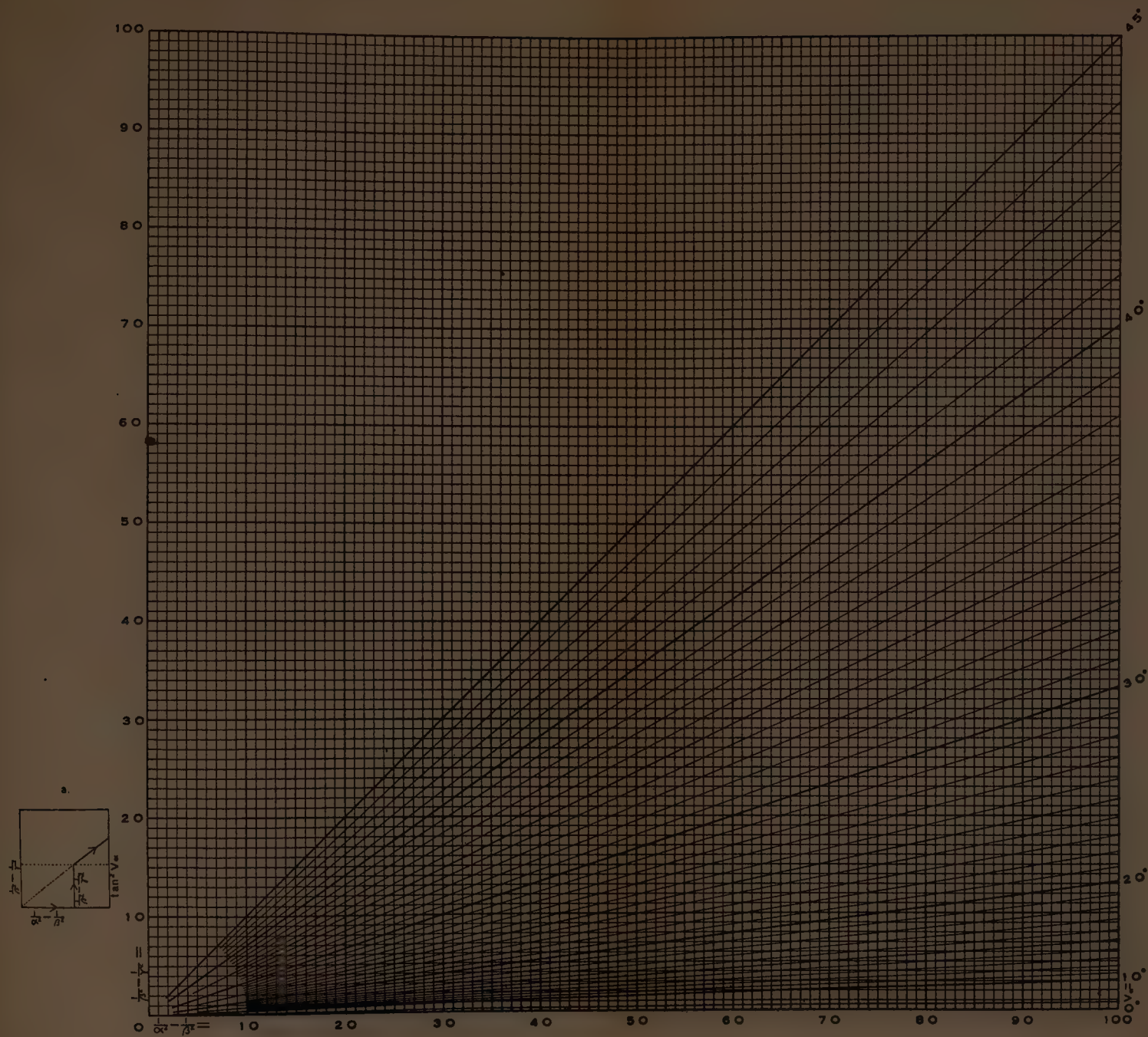




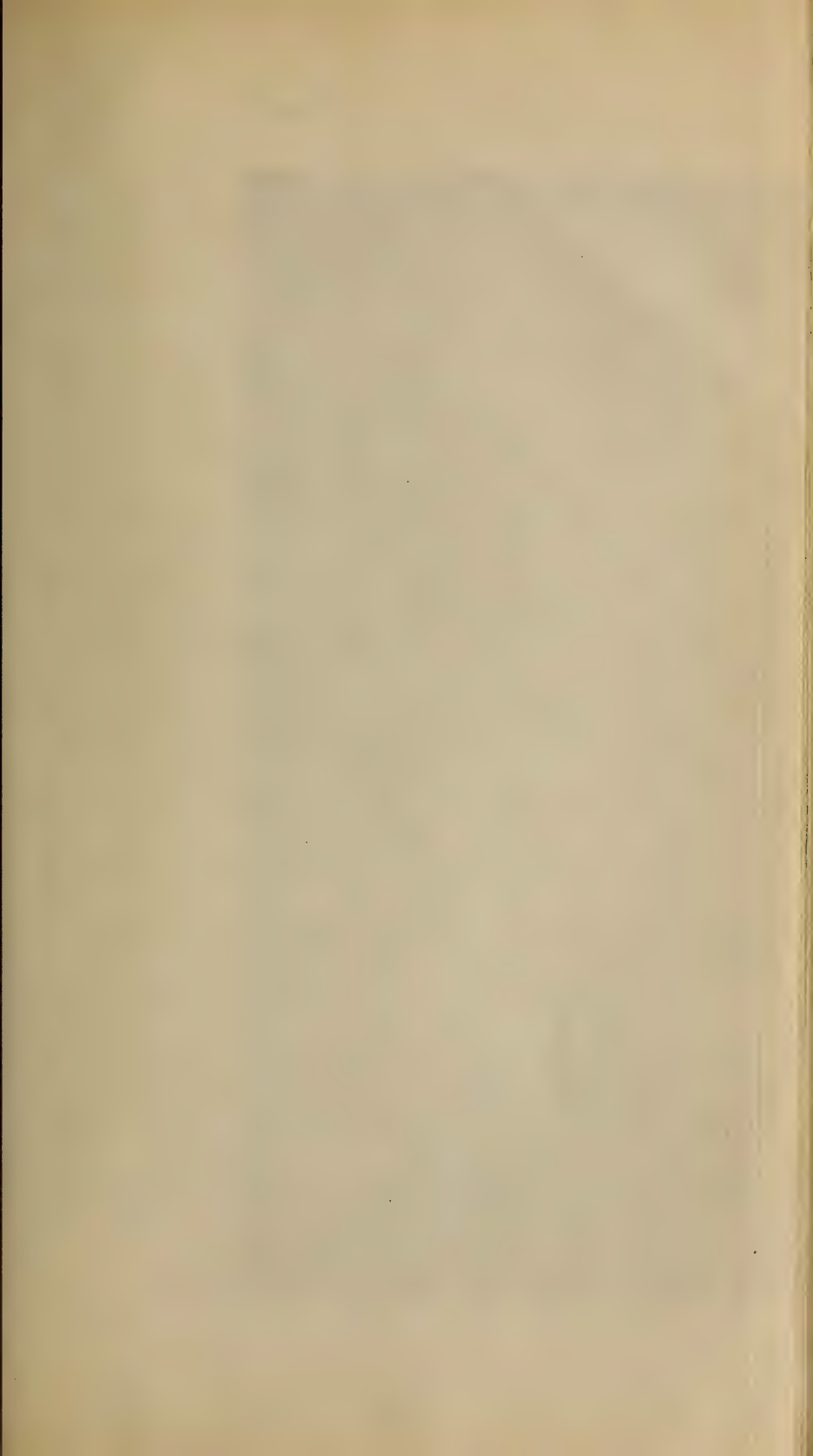


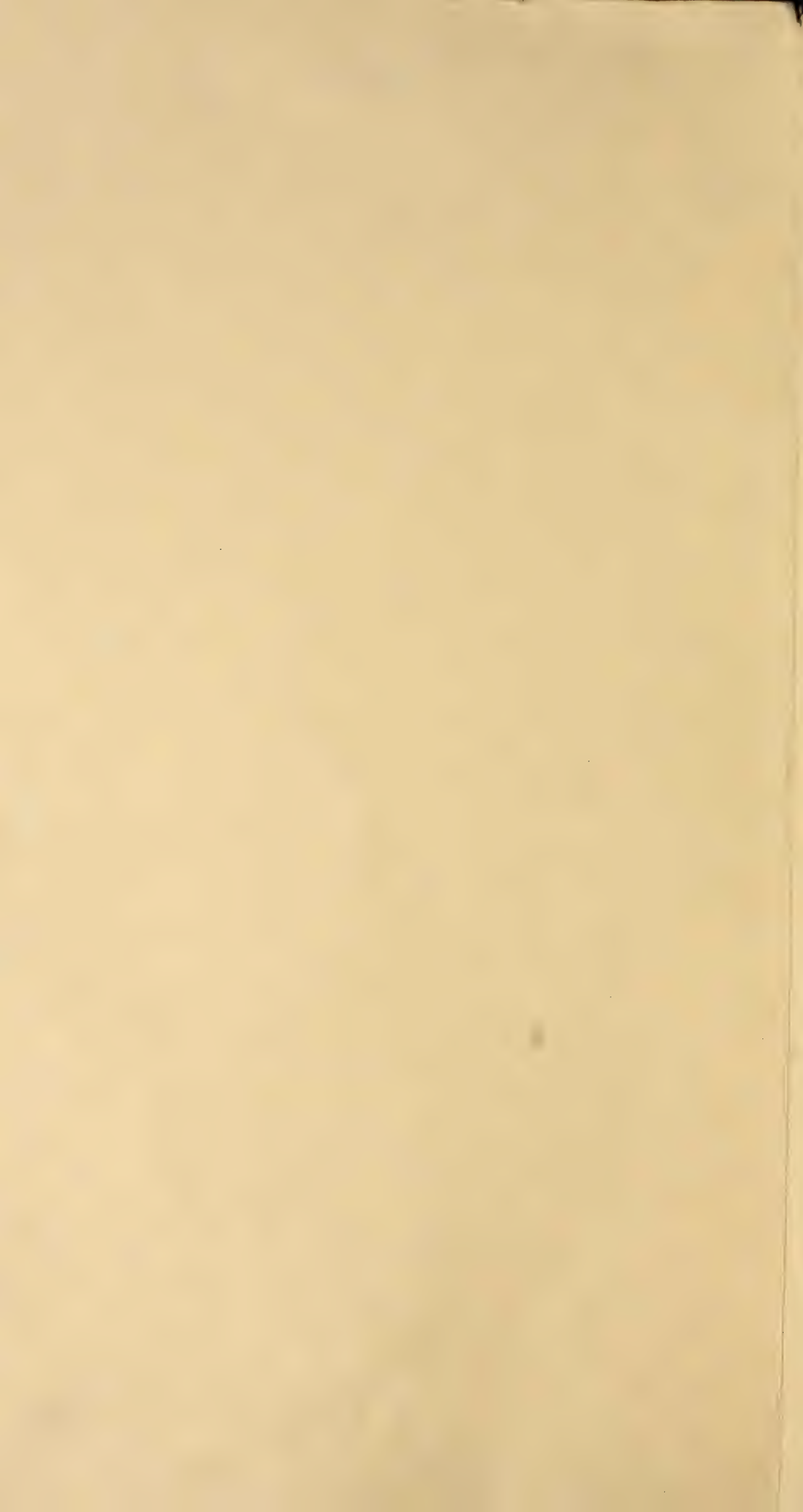


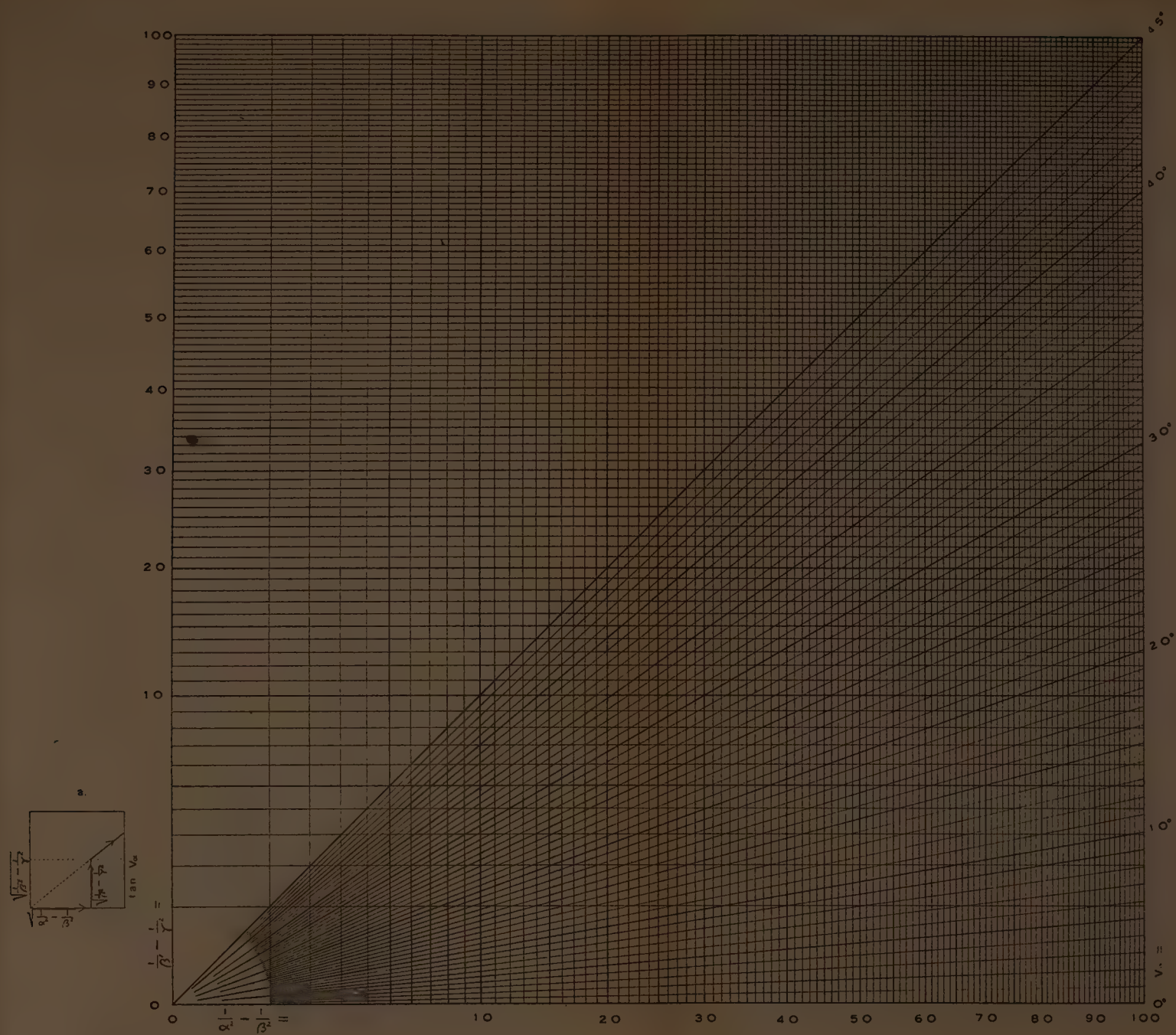


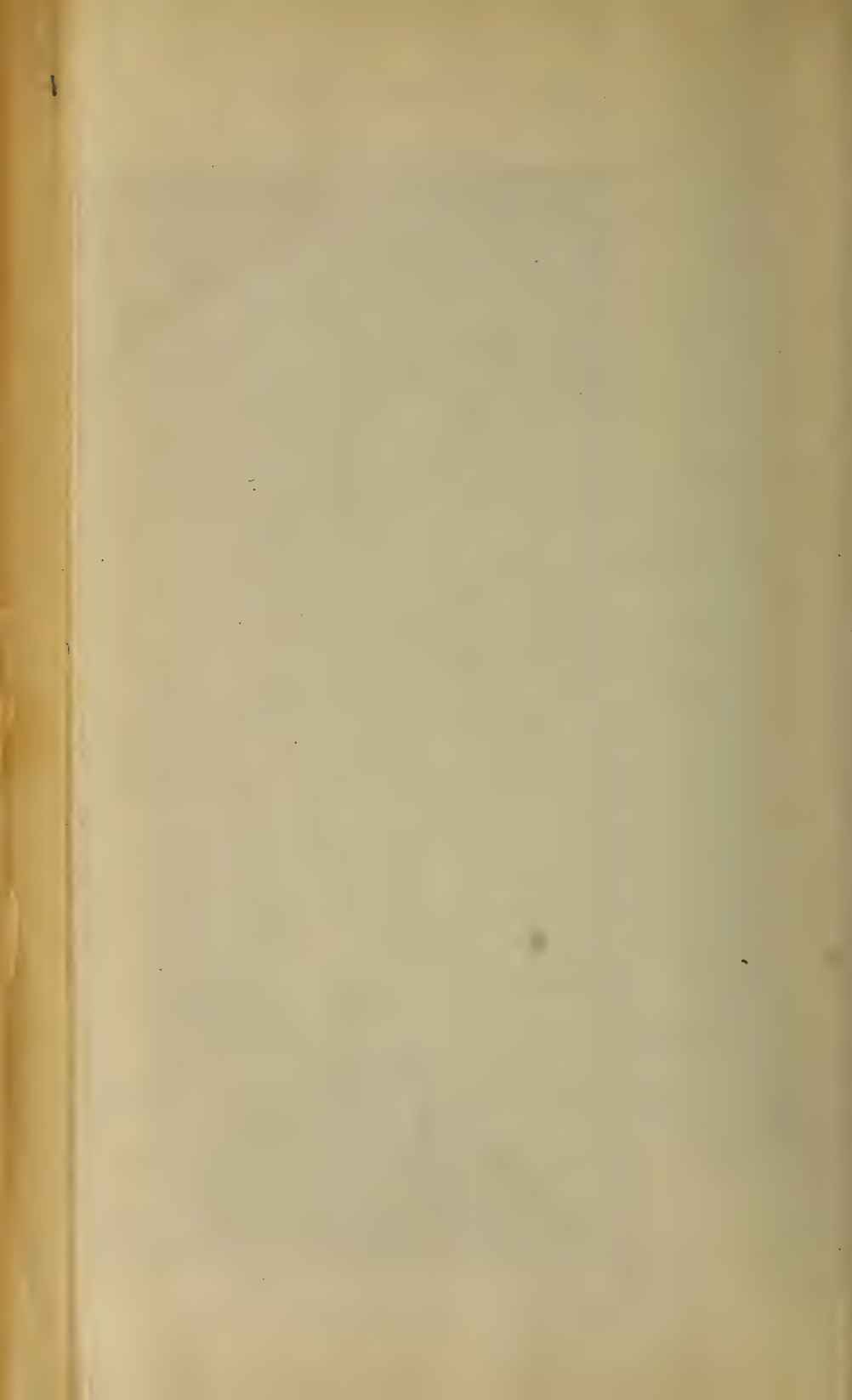


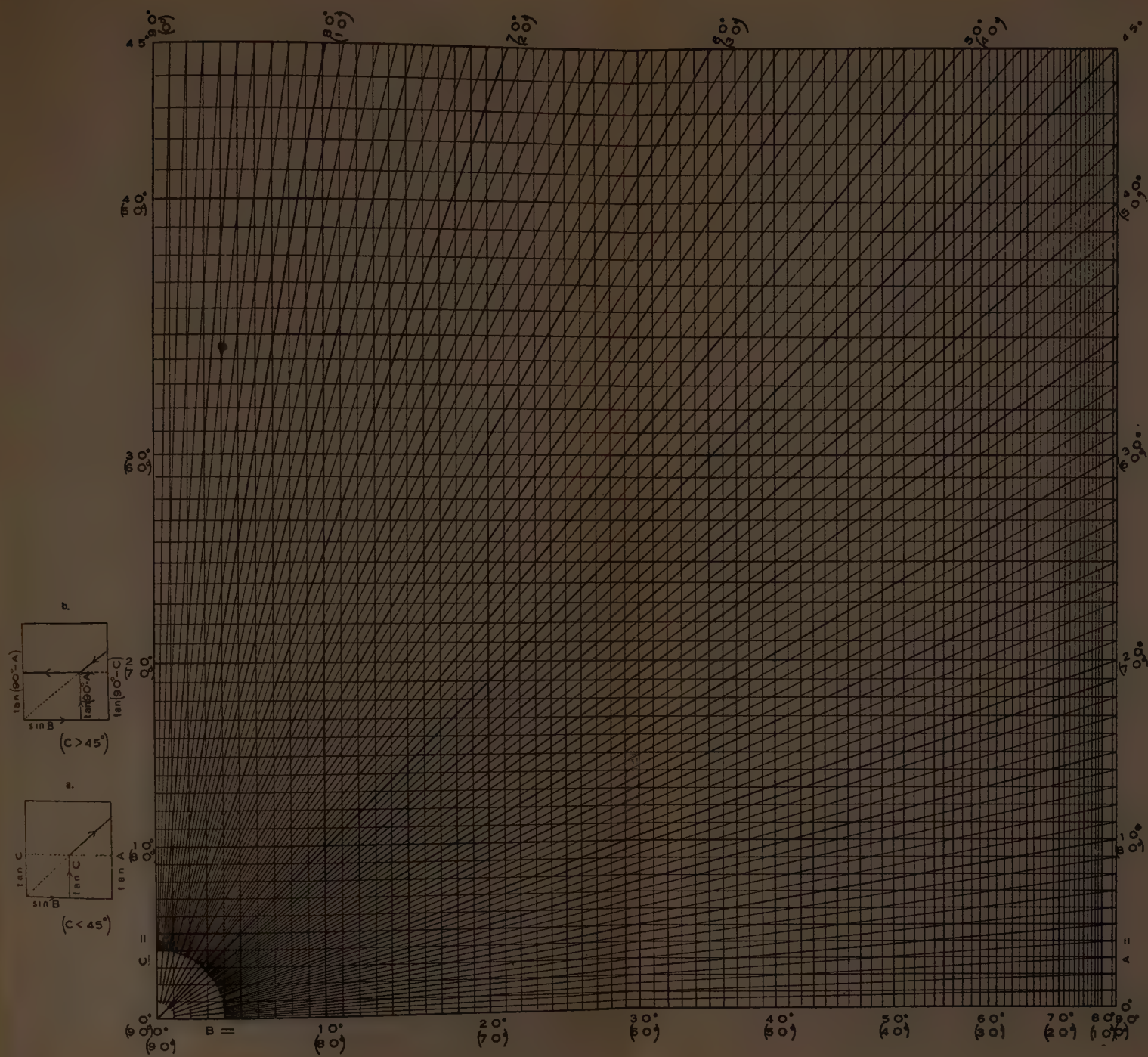


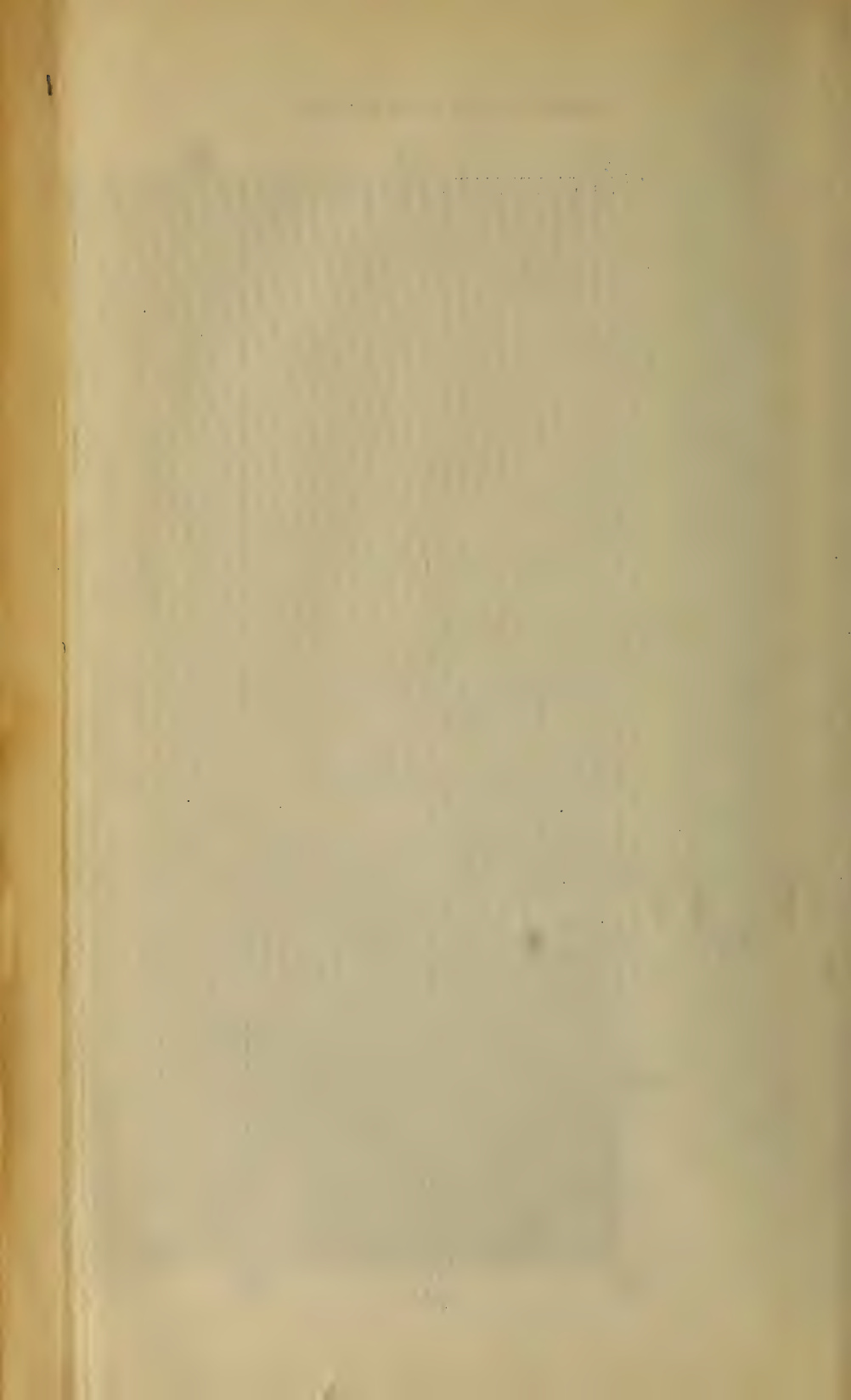


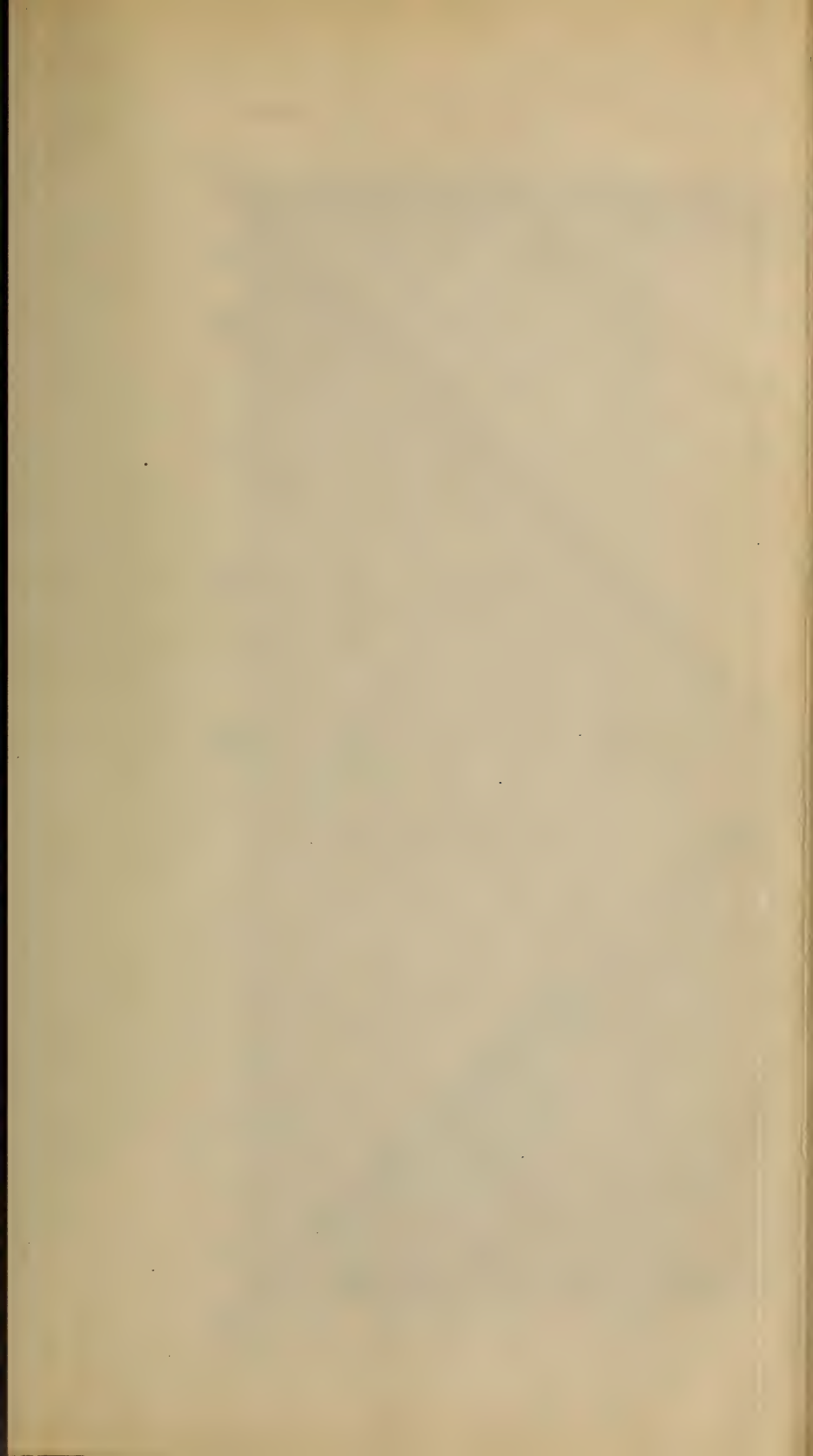


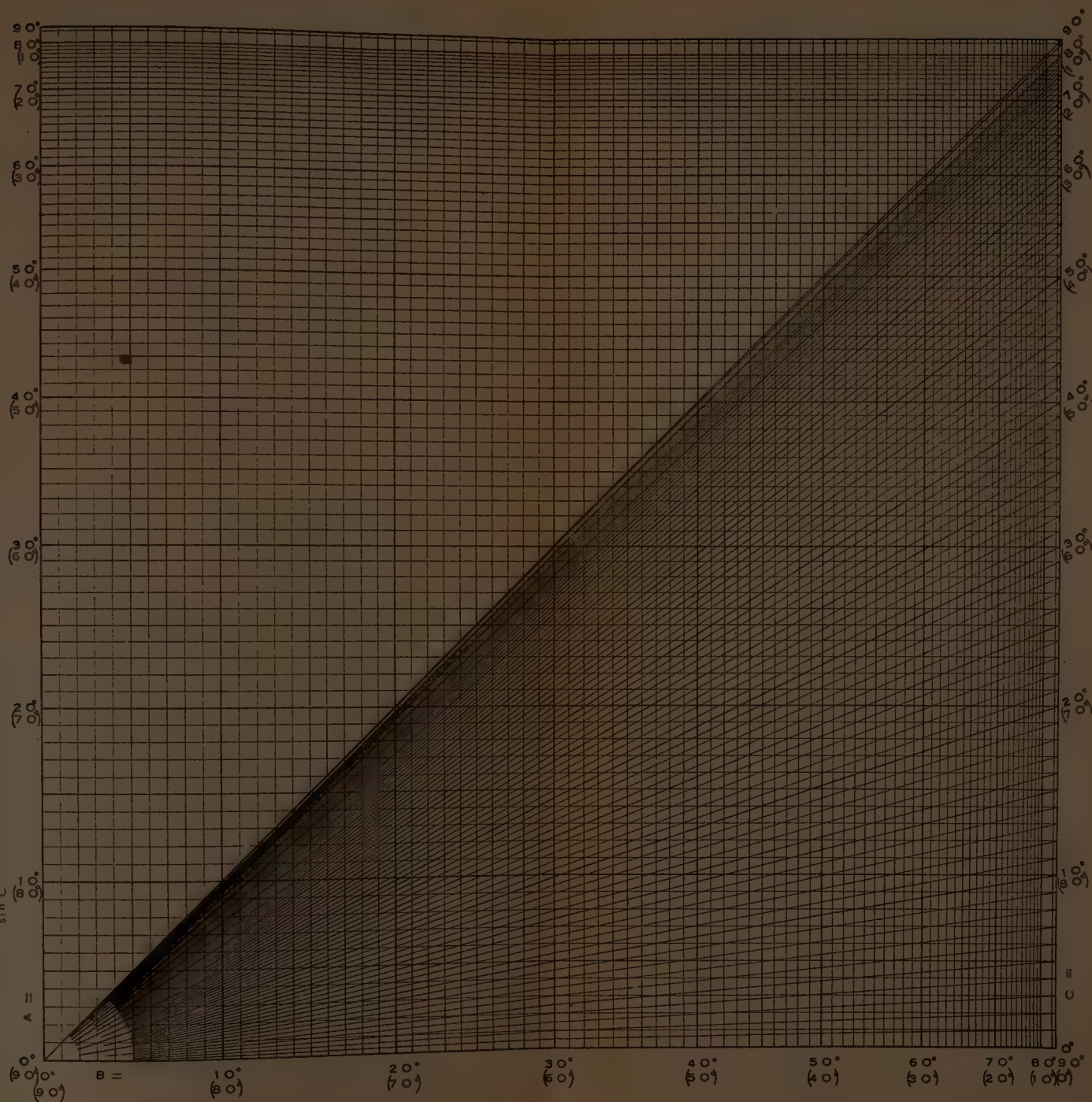












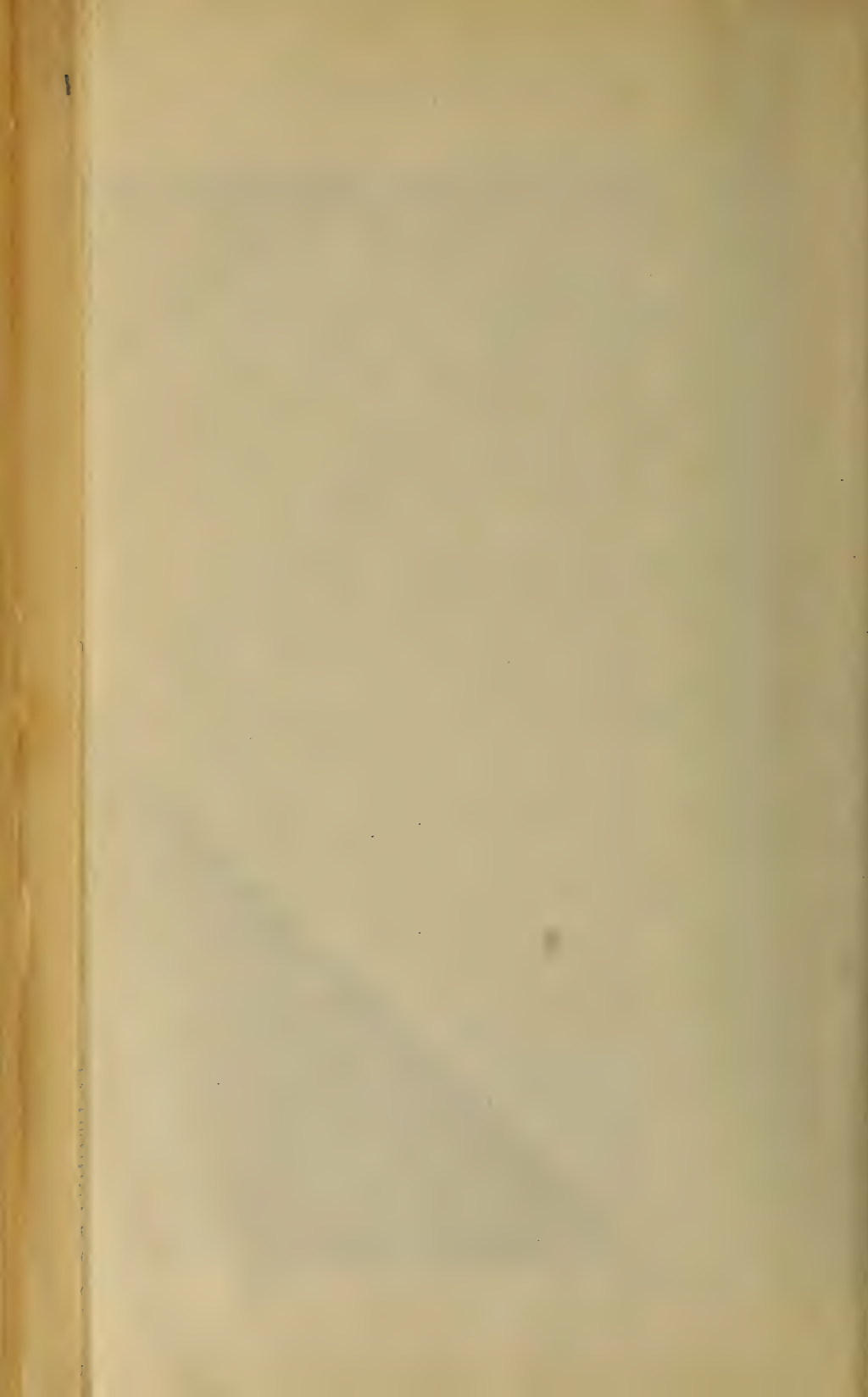
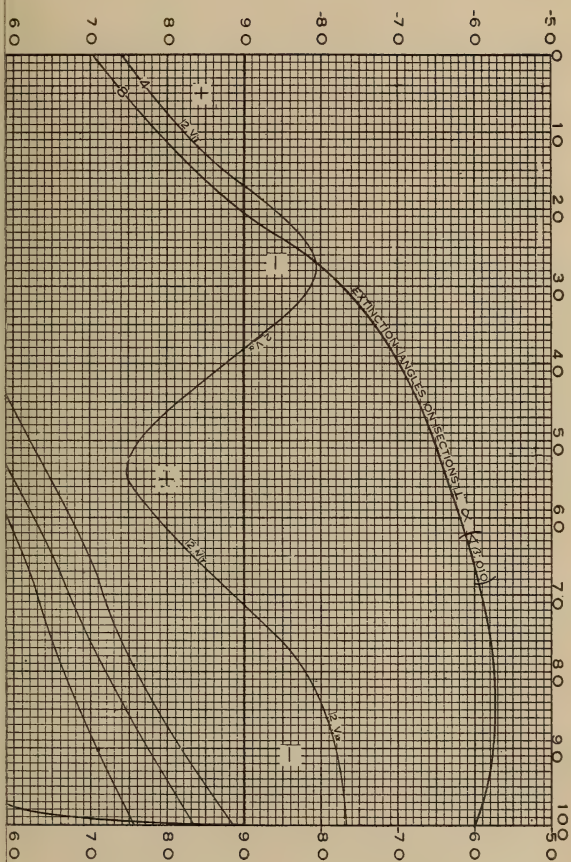
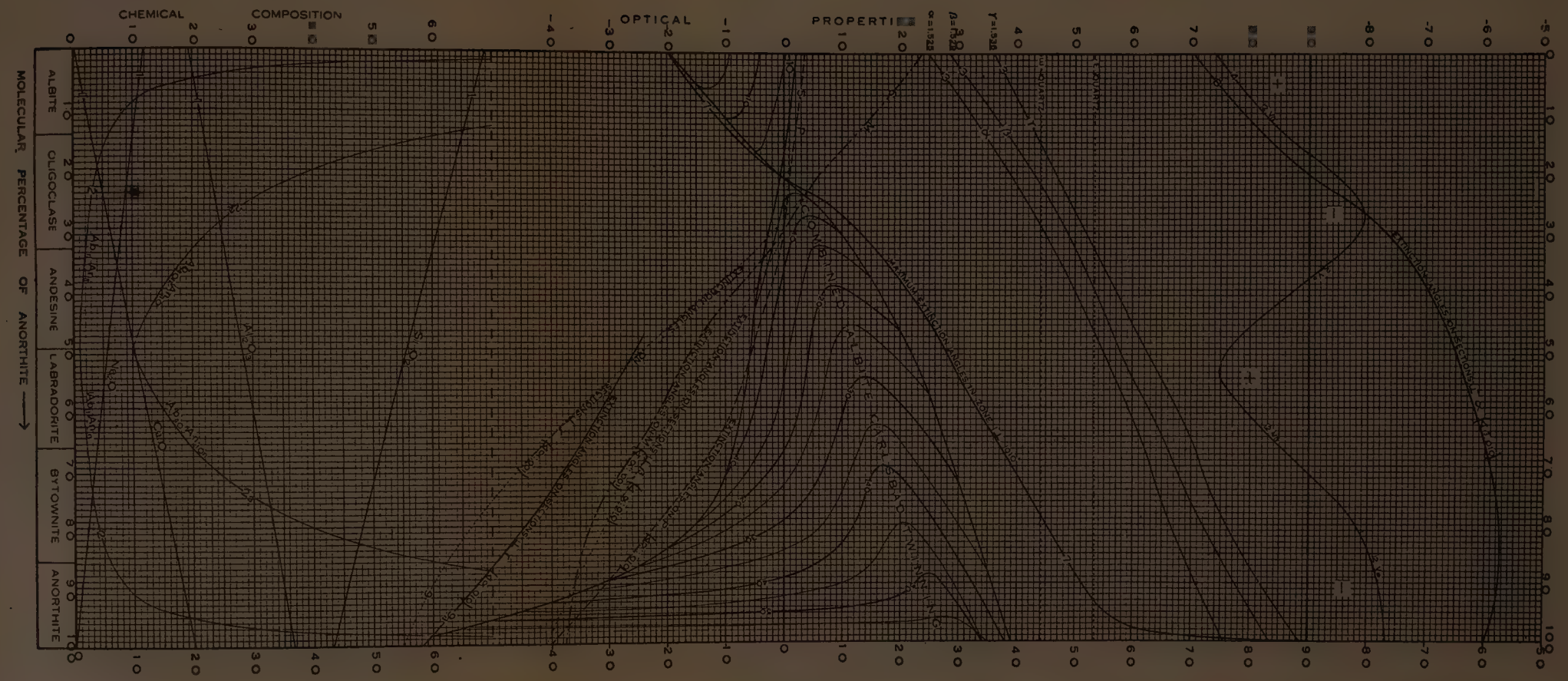
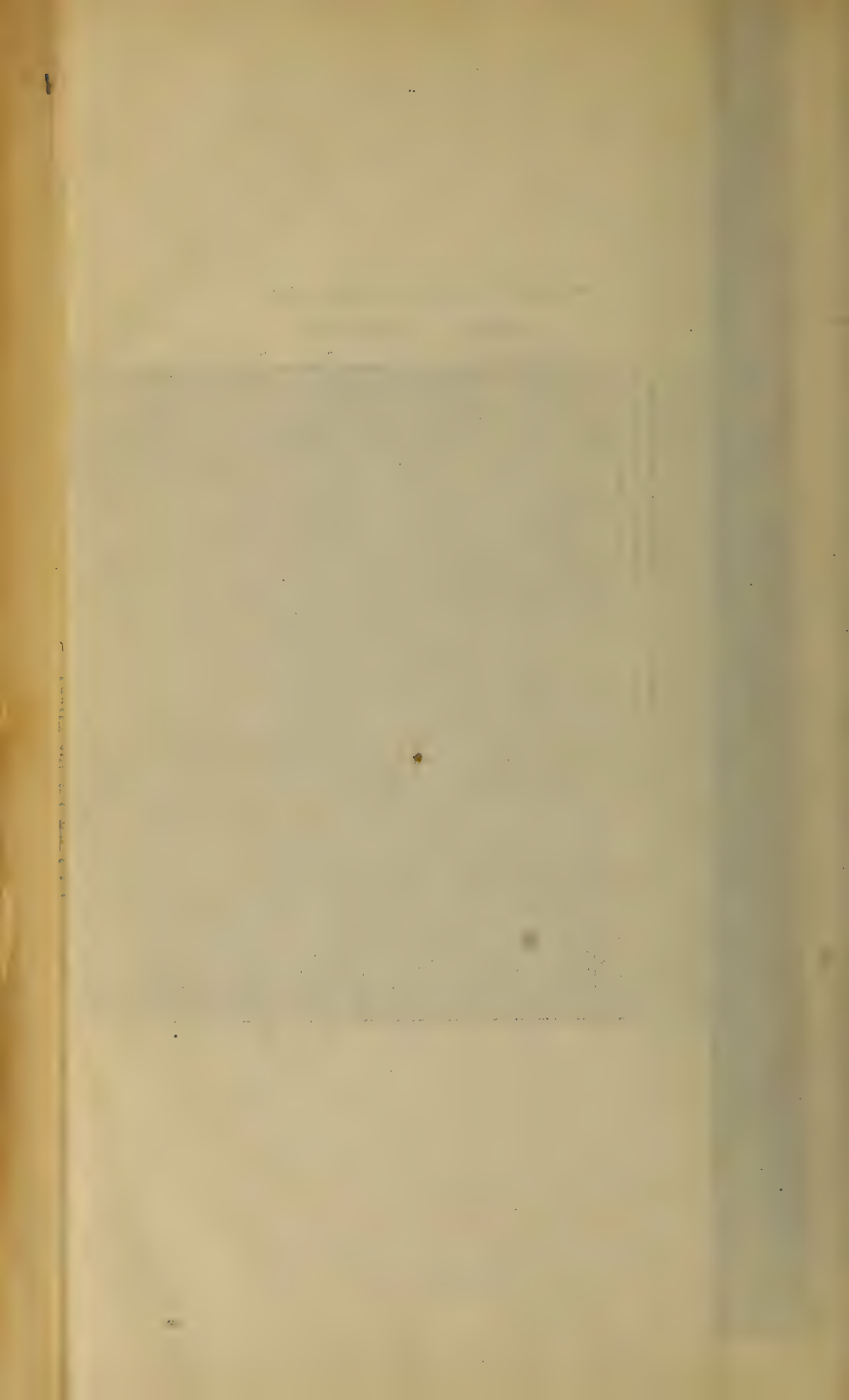


Plate X.







WARD'S NATURAL SCIENCE ESTABLISHMENT

A Supply-House for Scientific Material.

Founded 1862.

Incorporated 1890.

DEPARTMENTS:

Geology, including Phenomenal and Physiographic.

Mineralogy, including also Rocks, Meteorites, etc.

Palaeontology. *Archaeology* and *Ethnology*.

Invertebrates, including Biology, Conchology, etc.

Zoology, including Osteology and Taxidermy.

Human Anatomy, including Craniology, Odontology, etc.

Models, Plaster Casts and Wall-Charts in all departments.

Circulars in any department free on request; address

Ward's Natural Science Establishment,

76-104 College Ave., Rochester, New York, U. S. A.

EIMER & AMEND

Complete Laboratory Furnishers

Chemical Apparatus, Balances, etc.

C. P. and T. P. Chemicals and Reagents

Platinum Ware, Best Hammered Blowpipe Outfits
and Assay Goods

**WE CARRY A LARGE STOCK OF
MINERALS FOR BLOWPIPE WORK,
ETC.**

EST'D - 1851
203-211-THIRD-AVE
NEW-YORK-CITY

CONTENTS.

	Page
ART. L.—Some Lavas of Monte Arci, Sardinia ; by H. S. WASHINGTON	577
LI.—On the Use of Sealing Wax as a Source of Lime for the Wehnelt Cathode ; by NELLIE N. HORNOR	591
LII.—Dehydration and Recovery of Silica in Analysis ; by F. A. GOOCH, F. C. RECKERT and S. B. KUZIRIAN	598
LIII.—The Ascent of Lava ; by F. A. PERRET	605
LIV.—Solar Radiation ; by F. W. VERY	609
LV.—A New Occurrence of Cuprodescloizite ; by R. C. WELLS	636
LVI.—On the Crystallization of Willemite ; by C. PALACHE and R. P. D. GRAHAM	639

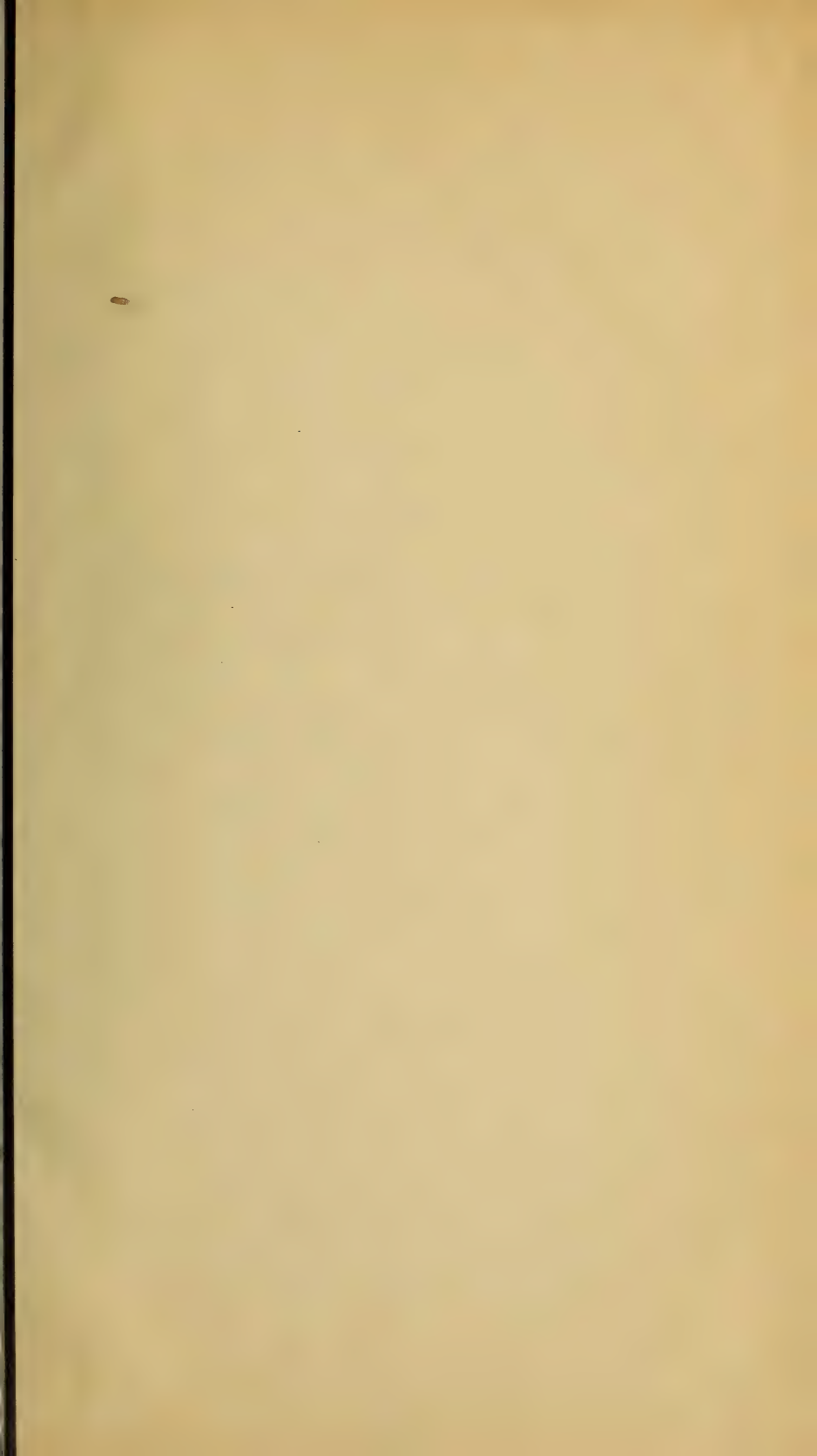
SCIENTIFIC INTELLIGENCE.

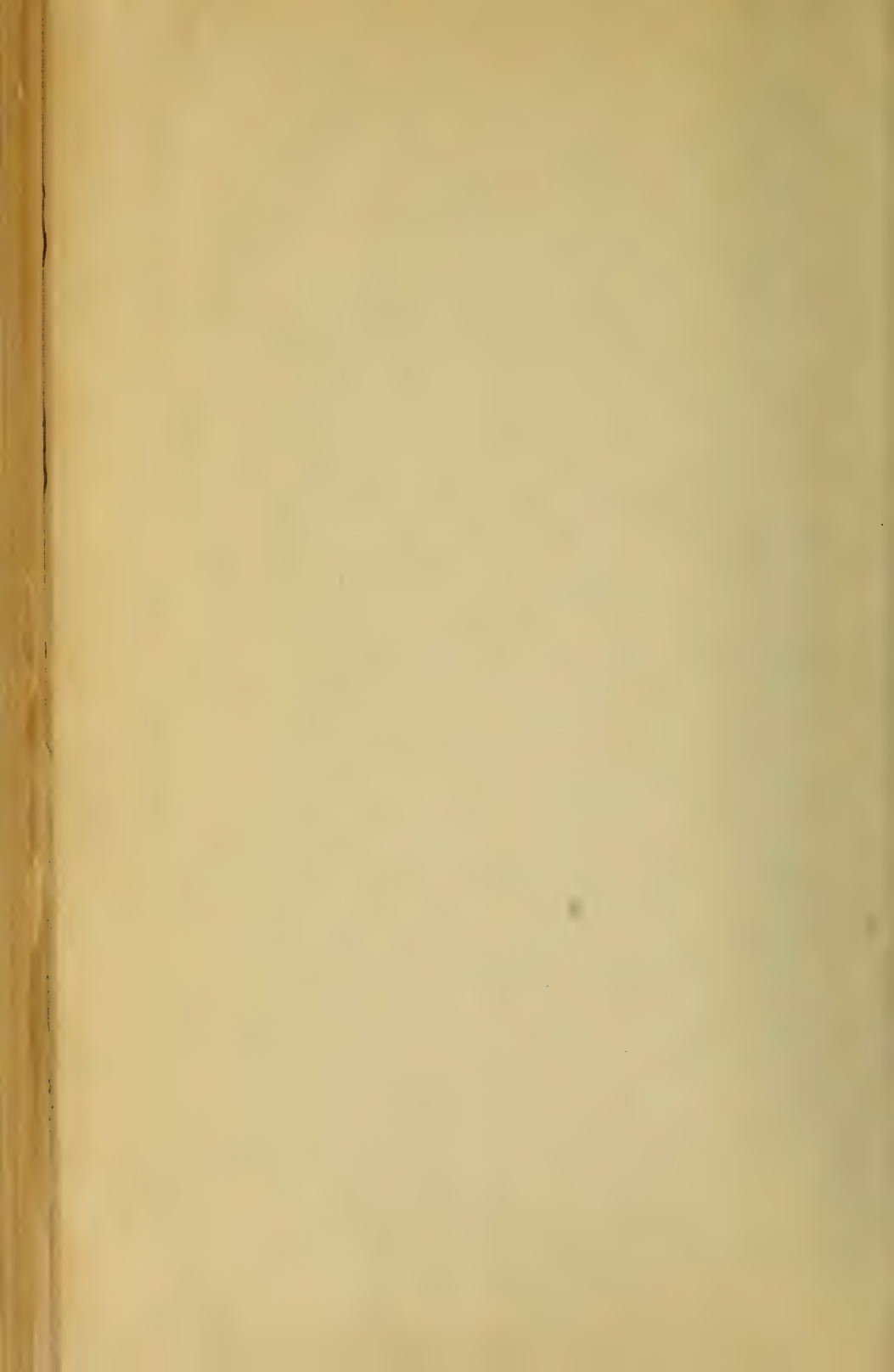
Chemistry and Physics—Action of Sulphur Trioxide upon Salts, W. TRAUBE, 644.—Volumetric Determination of Fluorine, A. GREEF: Behavior of Hydrogen towards Palladium, GUTBIER, GEBHARDT, and OTTENSTEIN: A New Era in Chemistry, H. C. JONES, 645.—Experiments Arranged for Students in General Chemistry, E. F. SMITH and H. F. KELLER: Chemical German, F. C. PHILLIPS: Spectrum of the Aurora Borealis, L. VEGARD, 646.—To Produce a Continuous Spectrum in the Ultra-violet, V. HENRI: The Gyroscope, F. J. B. CORDEIRO, 647.—Medizinische Physik, O. FISCHER: Wonders of Wireless Telegraphy, J. A. FLEMING, 648.—Principles and Methods of Geometrical Optics, Second Edition, J. P. C. SOUTHALL: Physical Measurements, A. W. DUFF and A. W. EWELL: Über kausale und konditionale Weltanschauung und deren Stellung zur Entwicklungsmechanik, W. ROUX, 649.—Annals of the Astrophysical Observatory of the Smithsonian Institution, 650.

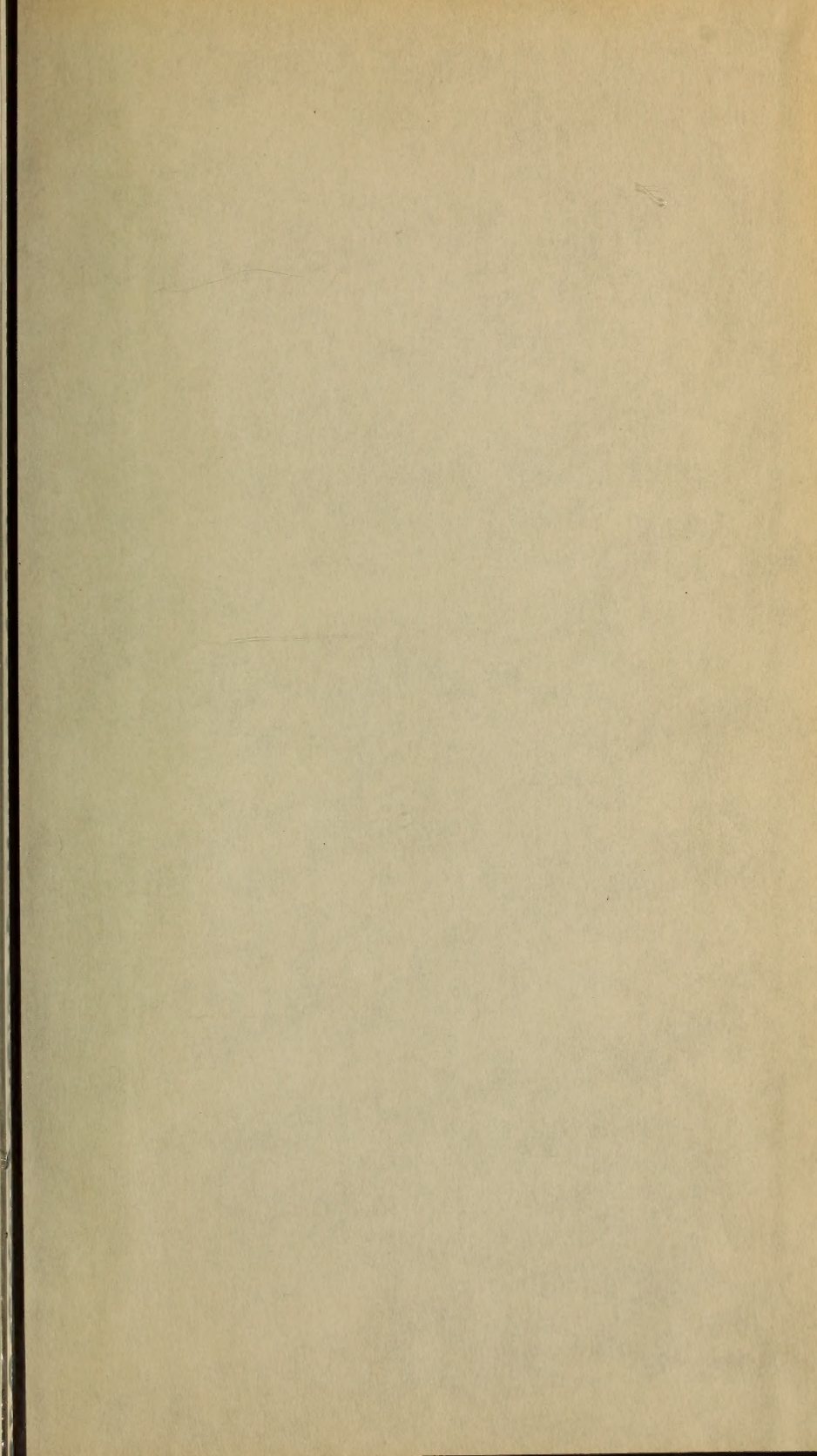
Geology and Mineralogy—Research in China, 650.—Fosseis Devonianos do Paraná, 652.—Monograph of the Terrestrial Palæozoic Arachnida of North America, 653.—The Heart of Gaspé; Sketches in the Gulf of St. Lawrence: Ninth Report of the Director of the Science Division, 654.—New Trilobites from the Maquoketa Beds of Fayette County, Iowa: New Paleontologic Periodical—Palæontologische Zeitschrift: Petrology of the alkali-granites and porphyries of Quincy and the Blue Hills, Mass., 655.—Geology and Ore Deposits of the Philipsburg Quadrangle, Montana: Gems and Precious Stones in 1912, 656.

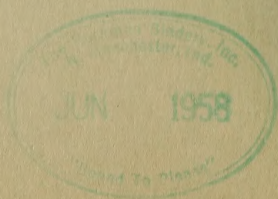
Miscellaneous Scientific Intelligence—National Antarctic Expedition, 1901-1904; Meteorology, Part II, 656.—Annual Report of the Board of Regents of the Smithsonian Institution, showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1912: Report on the Progress and Condition of the U. S. National Museum for the year ending June 30, 1912, 657.—Publications of the British Museum of Natural History: Publications of the Museum of the Brooklyn Institute of Arts and Sciences: National Academy of Sciences, 658.—Elements of Bacteriological Technique, 659.

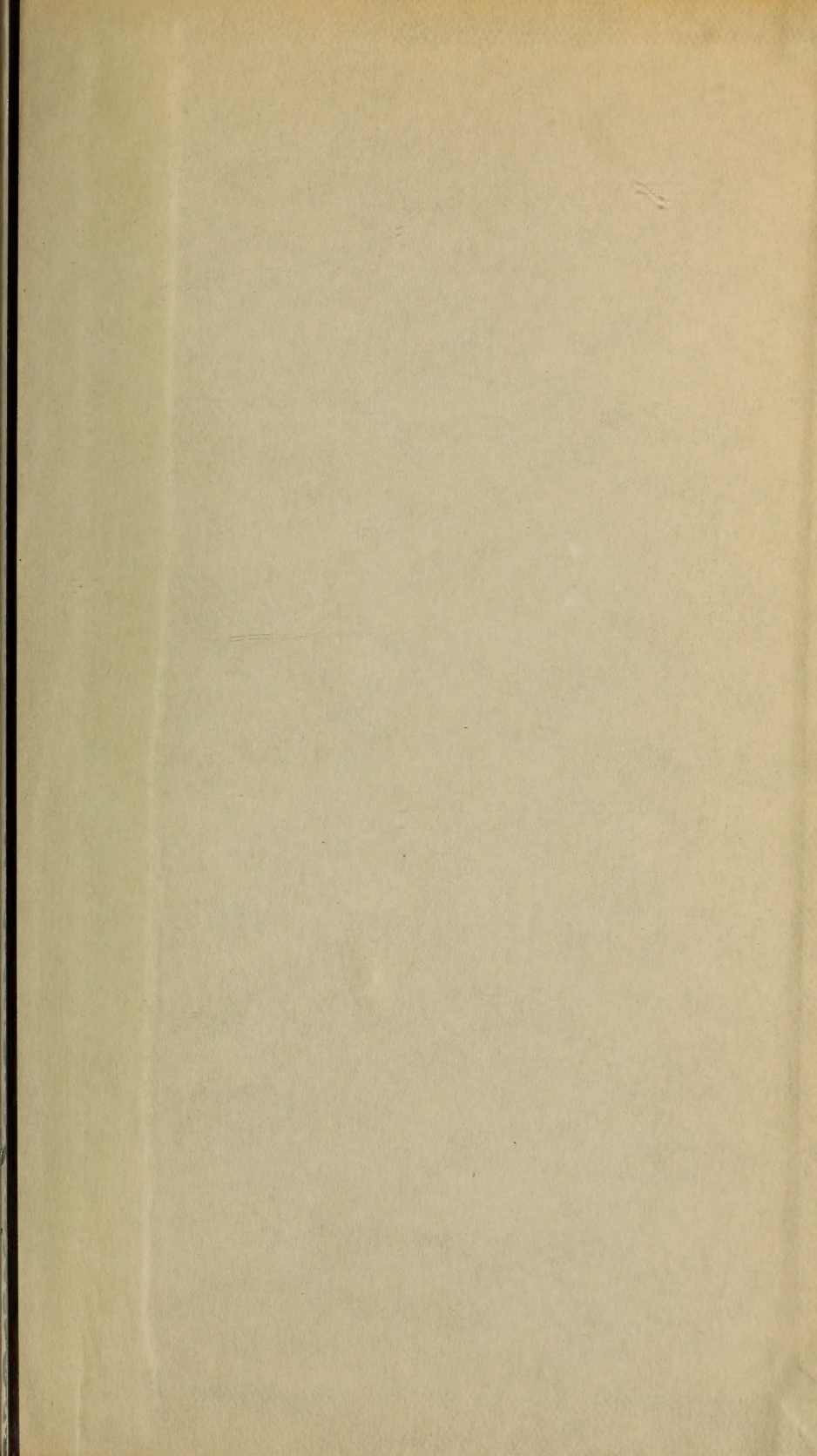
Obituary—A. R. WALLACE: W. H. PREECE, 659.











SMITHSONIAN INSTITUTION LIBRARIES



3 9088 01298 5875